HISTORY
OF
BRIDGE ENGINEERING

BY

HENRY GRATTAN TYRRELL

Alexander III Bridge, Paris

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PREFACE

PROFICIENCY in any art or science is not attained until its history is known. Many a student and a designer finds, after weary hours of thought, that the problems over which he studied were considered and mastered by others, years or centuries before, perhaps with better results than his own.

History is very fully taught in Schools of Architecture, but up to the present, very little time or thought has been given in the Engineering Schools to the History of Engineering, which is certainly quite as worthy of attention. The absence of such courses is generally ascribed to insufficient time and the dearth of literature. A need for this book is therefore evident, especially as there is at present no other on the subject in the English language.

A noted writer has said that "the most remarkable trend of modern thought notwithstanding the effervescent boastfulness of the present century, is an appreciation of the work done by those who have gone before. During this busy age of specialists in every profession, the active thinking men that can spare the time from bread winning, are engaged more or less in looking backward. Retrospection is as surely the watchword of the modern philosopher as was introspection of his mediæval brother. In the world of applied science no less than in the domain of ideas, we must reverse our mental telescopes if we would measure at its full the glory of human achievement. To aid in our investigations, the excavator, the archæologist, the ethnologist and the philosopher are constantly at work. In our longings to complete the history of the development of any art we must look to them to supply the missing link in the chain of human activities that connect us with the past."

An effort has been made to condense the subject, which might easily fill a thousand pages, into a small volume comparing in size with other text books, and for this reason, general references were prohibitive. As many quotations have been made from the writer's work, often without credit, footnotes refer to a few of the original articles. A hundred or more views of ancient and mediæval bridges were crowded out because of insufficient space, and only a few illustrations are included from a collection of about two thousand,

preference being given to recent types which are the most useful for present needs. While the book is essentially historical, it should be useful also for reference, especially in the selection of economic types, and the preparation of comparative designs and estimates. To assist in finding names and subjects, the more important ones are printed in black type.

Movable bridges are not included, as they are so different from others. They may be better considered as machines, and should be designed as such, with parts proportioned for service as found desirable from long observation and experience.

Much difficulty was experienced in the preparation of the earlier chapters because of the conflicting accounts of ancient writers and the difficulty in securing accurate dates. A large part of the volume is necessarily devoted to comparatively recent history, as the majority of bridges have appeared since 1760 when bridge building was revived in France under the direction of Perronet. Nearly all the great metal bridges of the world are the product of little more than half a century, since Mr. Whipple's investigations in 1847.

Most of the illustrations are from original diagrams, sketches and photographs, though a number are from the Engineering News, Engineering Record, and other technical papers and reports. I have been assisted in publishing this history by my wife, Maude K. Tyrrell, and especially so in making illustrations, and translations from foreign languages.

H. G. TYRRELL.

Evanston, Illinois, February, 1911.

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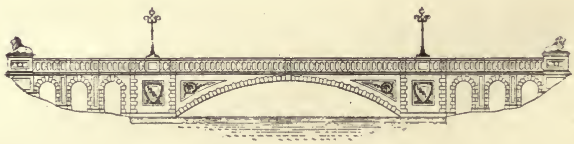

HISTORY
OF
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CHAPTER I.

EGYPTIAN, BABYLONIAN AND PERSIAN BRIDGES.
(Prior to 500 B. C.)

1. Bridges have existed since the dawn of human history. Primitive races were content with rude structures made of logs or trees thrown across the streams, or with slabs resting on stepping stones in the water, but the development of civilization and the beginning of commerce created a need for more secure and better crossings. Assyria and Egypt, which witnessed the origin of the human race, are the countries where the first traces of bridge construction have been found. The art of bridge building and the profession of civil engineering, whether known by its present name or a different one, are therefore as old as the races, and have been coexistent with the building of cities and the progress of civilization in all ages. The materials used then were much the same as now, the difference being chiefly in the forms employed.

2. Bridges are not mentioned in the Bible, and secular history contains little reference to the early ones of Babylonia, Assyria and Egypt, but existing ruins and the known state of civilization indicate that they were used. War between ancient nations, and the constant liability to hostilities were serious checks to progress, for in those days bridges were as much an invitation to the invader as they are now to commerce. Permanent ones were often undesirable, for cities and castles were surrounded by walls, outside of which were deep motes or ditches crossed only by movable platforms. Many of the best known bridges of ancient times were built during military

campaigns for the transportation of armies, and they are described among the achievements of their originators.

Assyrian Bridges.

3. The country adjoining the valleys of the Euphrates and Tigris rivers and their tributaries in Assyria was a very fertile region, capable of yielding large agricultural products and supporting a great population. Historians have variously estimated the population of Babylon from two to twenty millions. Nineveh and other cities were also large, and the urban residents must have depended upon the products of the surrounding country for subsistence. Elaborate systems of canals were used for bringing food supplies to the metropolitan centers, and existing remains show that the canals were often in double lines, 6 to 15 feet in depth, and 20 to 30 feet in width. These canals must have been crossed at frequent intervals by bridges corresponding in size and dignity with other buildings of the time. History mentions dams on the Tigris and the Euphrates, and the builders of dams would doubtless be familiar also with bridge building. The Tigris river dams for diverting water into irrigation canals, were encountered by the boats of Alexander 350 B. C.

4. The date when arches were first introduced is unknown, but they were used to some extent by ancient races, for in recent excavations at the supposed sites of the cities of Nineveh, Nippur and Babylon which were destroyed between 700 and 600 B. C., remains of pointed brick arched sewers were found, dating back to about 4,000 B. C. Similar sewer arches were also found (1,300 B. C.) under the ruins of the ancient palace of Nimrod in the city of Calah on the Tigris. Calah was 19 miles below Nineveh and was founded thirteen centuries before the Christian era. In the ruins of Khorsabad, 15 miles from Nineveh, semicircular voussoir arches of 13-foot span were found over gateways in the city wall, dating back to

at least 720 B. C. These are some of the earliest known traces of the true arch, though false arches over doors and gateways have also been discovered in ancient ruins. True arches were made of wedge shaped bricks in spans up to 15 feet, but their theory appears to have been unknown until a later period. Most of the early forms were really corbels, bracketed from the adjoining piers and meeting at the span center, exerting only vertical reactions. The constant horizontal thrusts from true arches tending to overturn their abutments caused builders in early times to use other and more permanent forms.

5. History states that **Babylon** was 15 miles square and was surrounded by a brick wall 350 feet high and 87 feet thick, on which were three hundred and fifty towers for defense. A great ditch surrounded the city outside the wall, and the earth excavated from it was used in making brick. The River Euphrates, which flowed through the center of **Babylon,** had quay walls at either side, of the same thickness as the city wall, and outside of the city was a great lake or reservoir 52 miles square and 75 feet deep, containing the overflow from the river for use in times of drought. It is further stated that 100 years after the flood (2,200 B. C.) in the time of Nimrod, third ruler after Noah, the river was spanned in the center of the city by a **single brick arch,** one furlong (660 feet) long and 30 feet wide, the great quay walls at the side serving as abutments for the arch. At the ends of the bridge were two palaces, which were connected also by a brick tunnel beneath the river. The bridge probably endured as long as the city, for if it had fallen, the historian describing it would also have described it fall. It must have been made of brick, as that was the only building material of Babylon. A prototype for this bridge may have been found in some natural arch like the great Augusta Bridge in Southern Utah, which is 265 feet high and 30 feet wide, with a clear span of 320 feet.

6. The earliest record of a wooden bridge is given by Herodotus, "the father of history" (484 B. C.), describing one built 783 B. C. over the **Euphrates River in Babylon** during the reign of Nitocris who succeeded Semiramus as Queen of Assyria. The bridge had stone piers connected with wooden platforms which were removed at night to prevent thieves from entering the city. Its width was 35 feet and length 660 feet (one furlong). Another writer says that the piers were built "with great skill on the sandy river bottom with arches of hewn stone fastened together with iron chains and melted lead." While building the piers, the river was diverted from its course into an artificial lake or basin 13 miles square, with high artificial banks to prevent the adjacent country from being inundated, and two outlet canals discharged the overflow. One historian relates that the bridge was roofed over and was equal in beauty and magnificence to any other structure in Babylon, but no trace or remains of it have ever been discovered. Diodorus Siculus says that it was built under the direction of Queen Semiramus.

7. **The Caravan Bridge** over the River Meles at Smyrna in Asia Minor, is believed by archeologists to be one of the very oldest in existence. The river does not exceed 40 feet in width, and it is crossed with a single span. On the banks of this river, Homer lived and played when a boy twenty-nine centuries ago, and Saint Paul on his journey into Smyrna probably entered the town over Caravan bridge. The parapets and pavement have been renewed within the last two centuries, but the remainder of the bridge is in its original condition.

Egyptian Bridges.

8. Stone arches were found over the entrance of the Great Pyramid of Ghizeh near Memphis in Egypt, dating back from 3,100 to 4,200 B. C., but these were not true arches, being made

of single sloping stones meeting over the center of the opening. A tomb was also found at Ghizeh, 26 by 30 feet in plan and 53 feet deep, which is supposed to have been covered about 600 B. C. with a masonry arch. Brick arches of very primitive form were found in the ruins of Thebes on the river Nile, which were probably built about 2,900 B. C. The seventy or more other pyramids in the vicinity of Memphis are made of limestone and granite brought from quarries 500 miles up the Nile. The largest pyramid is 764 feet square at the base and 480 feet high, and the building of it is said to have required the services of one hundred thousand men for twenty years. The builders of the pyramids were expert in handling materials, and must have been able to erect bridges or other structures to suit their time and needs. They used heavy timbers for moving and transporting the stone, and were as well able to use stone for bridges as for pyramids. The early Egyptians were great engineers and builders, as is shown by the annual diversion of water from the Nile into great storage reservoirs for use in dry seasons. They had "Joseph's Canal" for irrigating lower Egypt, and as early as 1,450 B. C., had a canal joining the Nile and the Red Sea. Some authorities say that the Egyptians crossed the rivers on floats drawn by swimming horses, and in Genesis it is stated that the water of the Red Sea was parted and Pharaoh's army marched over on dry ground without need for either floats or bridges. Notwithstanding the lack of positive records, it is probable that so great a people and race of builders must have had bridges over their canals and rivers.

Grecian Bridges.

9. Bridges of ancient Greece built by the Cretians in prehistoric times, like that of a later date on the island of **Euboea over the Euripus river,** erected during the Peloponnesian war, 425 B. C., had heavy piers and abutments connected with

wooden planks, or like the **bridge at Assos** (Fig. 1), had stone lintels doweled together on stone piers. The Assos bridge had seventeen elongated diamond shaped piers, 10 feet apart

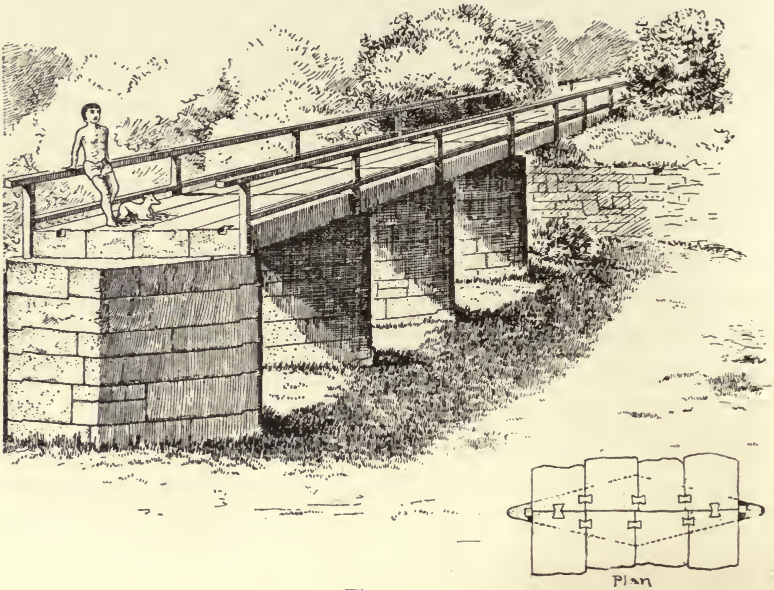


Fig. 1.

on centers, with stone lintels 20 inches thick and 24 inches wide, doweled together. A similar bridge (Fig. 2) is over the **Valley of Flamingos,** Fayal, Azores. In later years piers were built with the upper stone courses overhanging, to meet in the center of the span in the form of a false triangular arch.

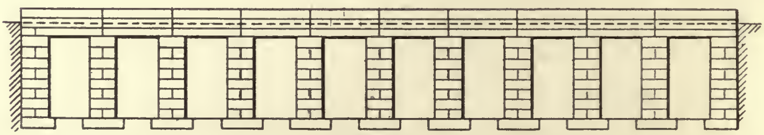


Fig. 2.

Bridges at Metaxidi, Sparta, and in Messenia over the river Pamisus are built in this way. Other stone bridges of un-

known date remain in the vicinity of Phlius and Mycenae. The semicircular arch afterwards used by the Romans, is a development of the earlier false arch of the Greeks.

Persian Bridges.

10. One of the oldest, if not the very oldest, existing bridge in Persia is at **Dizful** in the Province of Khuzistan over the river Diz. It is 1,250 feet long and is still in a fair state of preservation (Fig. 3). It has twenty pointed arches 23 feet long, between piers 29 feet thick. The large pointed arches and the minor ones through the piers above the level of the main springs, are characteristic of Mohammedan architecture, and are believed to date from 350 B. C. in the

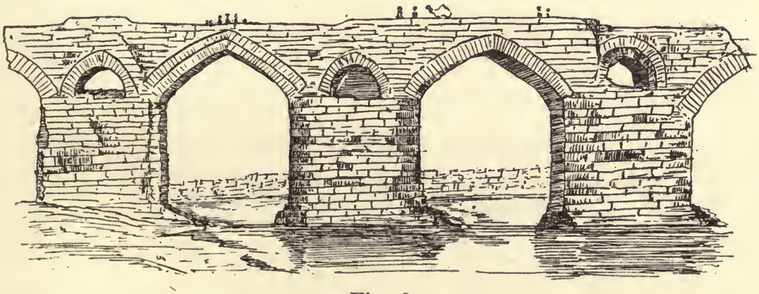


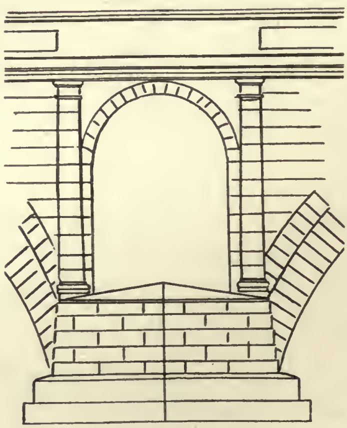
Fig. 3.

reign of the later Archaeminid Kings over Iran, though a French historian attributes it to the fourth century A. D. A similar bridge 1,700 feet long exists at **Shuster** (Chouster) in Persia over the Karun river, which suggests that the Gothic or pointed arch may have originated in Persia. The Shuster bridge is made of brick and it follows a zig-zag course across the river with about a dozen bends or angles.

11. Pontoon bridges were used by the ancient Persian Kings Cyrus, Darius and Xerxes 536 to 480 B. C., and earlier ones of unknown date or origin are referred to by Homer, who lived about 880 B. C. (See Pontoon Bridges.)

Chinese Bridges.

12. Records of ancient bridges in China have not been preserved, but masonry arches are known to have existed 2,000 B. C. The Chinese used both slab and arch construction, and were either the earliest bridge builders or contemporary with the Babylonians. Bridge construction in that country is therefore as old as any other art. The Chinese were great builders, for the wall of China, completed 214 B. C., is 1,500 miles long and 50 feet high in many places, and is the largest artificial structure on earth. Arches were used for carrying the wall over streams and rivers, and smaller arches over doors and gateways through the wall.



PONTE ~~ROTTO~~ FABRICUS

CHAPTER II.

ROMAN BRIDGES, 700 B. C.—500 A. D.

13. The bridges of the Romans have shown the greatest permanence, since at least twenty of them remain. Not less than eight bridges crossed the Tiber river at Rome and many others were scattered throughout the empire. For two thousand years or more they have withstood floods, earthquakes and the violence of war, and many of them are still in a good state of preservation as models for succeeding ages. The Tiber has experienced at least thirty disastrous floods, and the wonder is that any bridges remain. They were designed without much theoretical knowledge of their stresses and were proportioned by judgment or empirical rules, but they show great merit both in design and construction, and have hardly been excelled. The arch stones were often so carefully fitted that they appear to have been ground together, and in these joints mortar was not generally used, but the stones were united with iron clamps. It is said that Roman builders were required to make repairs on their bridges and keep them in good condition for a period of forty years, and the final payments were withheld till after that time, all of which clearly shows their purpose of constructing works of permanence. Slave labor was probably employed in bridge building as in other public works of the ancients.

14. The great era of Roman bridge building began with the construction of the Roman highways. This people foresaw that the development of their domain depended largely on the condition of their roads, and in warfare against other nations,

the bridge builders were in the lead of the Roman army Not including the footways at the side, their roads had a width of 14 to 18 feet. The Flaminian Way commencing at the Milvian bridge at Rome, terminated at the bridge in Rimini, and the Appian Way, which was 350 miles long, was built in the years 312 B. C. to 30 B. C., and was in good condition until 500 A. D. Other Roman roads were the Aurelia, Aemilia, Cassia, Latina, Salario and Valeria.

15. During the seventh and sixth centuries B. C. the piers of stone bridges in Italy were frequently corbeled out till they met at the span center, forming a pointed false arch, and those at Cora, Vulci and Bieda were of that type. Between 600 and 500 B. C. the semicircular true arch began to appear, after which, all Roman arches were of that form. The true arch is known to have existed in Greece in tombs and domes as far back as the days of Pericles, 450 B. C., but it was not used for bridges in that country until a later period. The city of Athens was adorned with splendid buildings, but there is no trace or evidence of bridges in the city, and the river Cephisus must have been crossed by wading. At a later period, a bridge was thrown across this stream by Emperor Hadrian, between the territories of Attica and Eleusis, on the most frequented road in Greece. The Roman bridges were noted more for their durability and permanence, than for their length of span, which rarely exceeded 70 to 80 feet. Piers were usually very thick, often one-third of the adjoining openings, and the failure of one arch in a series did not cause the others to fall. The excessive pier thickness was, however, a serious obstruction to the water, and often caused the foundations to be undermined. Above the springs the piers were usually pierced with smaller openings, and stones were sometimes left projecting from the piers for the support of temporary centering, as on Pont du Gard Their bridges generally

had an uneven number of openings, with span lengths decreasing from the center to the ends, and the springs of adjoining arches were usually at the same level. They frequently had triumphal arches over the roadway, as is shown by those at Antioch, Magnesia, Martorell, Alcantara and Fabricus, and many were further adorned with statues.

16. The materials in Roman arches were usually tufa, peperino and travertine, with a filling of Pozzuolana cement. Tufa stone is a mixture of volcanic ash and sand, and peperino, a conglomerate of ash, gravel, limestone and broken lava. Travertine is a creamy white limestone, and it has great durability when laid on its natural bed. Concrete was made with Pozzuolana cement, which is a reddish earth found at Pozzuoli near Naples, and also at Rome. The earth was pulverized and mixed with lime to form hydraulic cement. Bridges were frequently faced with blocks of travertine, and ring stones laid dry without cement.

17. One of the earliest examples of arch construction is the **Cloaca Maxima,** a large arch canal or stone sewer built by one of the Tarquins B. C. 615, to drain a tract of marshy ground between Palatine and Capitoline hills in Rome. It ran from the valley of the Circus Maximus, emptying into the Tiber below the island, and the reclaimed land afterwards became the Forum. The arch is formed of three concentric rings of volcanic stone put together without mortar. It is 1,740 feet long, and at the river end is 15 feet wide and 11 feet high, while at the upper end it is only 7 feet wide and 9 feet high. The walls contain large stones, some of them 8 feet long, 3 feet wide and 2½ feet thick. A new section 365 feet long, back of the Forum, was discovered in the latter part of the nineteenth century. The sides were probably walled up as early as 800 B. C., but the arch covering was added at a later period.

The Bridges of Rome.

18. The eight known bridges of Rome are Sublicius (621 B. C.), Aemilius (178 B. C.), Milvius (100 B. C.), Fabricius (62 B. C.), Cestius (46 B. C.) Aelius (136 A. D), Janiculanus (260 A. D.), and Triumphalis or Vaticanus.

(1.) The first wooden bridge of the Roman period of which any record exists, is the **Pons Sublicius** (Fig. 4), built according to Plutarch, by Ancus Martius, and so arranged that the floor could be removed. It is generally believed to be the first bridge over the Tiber at Rome, though some historians endeavor to show that a bridge existed on the site, long before

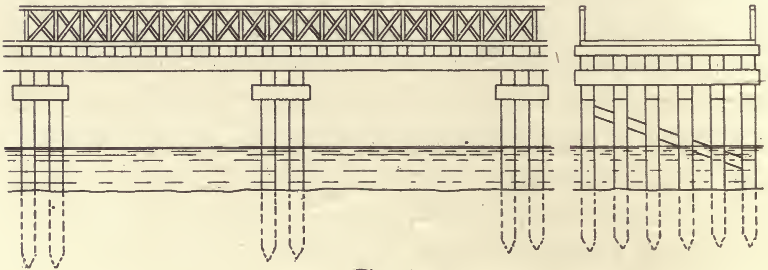


Fig. 4.

621 B. C., explaining that the work of Ancus Martius was merely a restoration. Pons Sublicius is noted for the legend of its defense by Horatius Cocles, a Roman knight who saved the city against the Etruscans under the leadership of Lars Porsenna B. C. 598. It is referred to by Lord Macaulay, "How well Horatius kept the bridge in the brave days of old." The bridge was destroyed about 500 B. C., but was twice restored by the Chief Priests. One historian states that it was rebuilt of stone in the seventh century B. C. In the year 23 B. C. it was washed out by a flood and again in the time of Antoninus Pius, 140 A. D., but each time was rebuilt, and the ruins of the last structure remained till 1877, when they were removed to clear the river channel As the word "Sublicius"

means piles, it is generally believed to have been of hewn timber, supported on piles, and neither nails or iron of any kind to offend the river gods, were used in its construction. Some authorities, however, think that the piers were stone, with a superstructure of timber arches. It was probably not over 600 feet in length, for on its site now stands the iron bridge Ponte Sublicio. Another writer says that this bridge was reconstructed of stone by Aemilius Lepidus, the last censor under Augustus, but was again carried away by a flood in 780 A. D. It was the custom in early times to cast human beings from Pons Sublicius as sacrifices into the Tiber, but in later years during the Ides of May twenty-four rush images were used instead.

(2.) A period of 400 years elapsed with no records of bridge construction, until B. C. 192, when two wooden ones were thrown across the Tiber at the site of Fabricius and

Fig. 5.

Cestius. These were followed in 178 B. C. by a stone arch bridge on the site of **Ponte Rotto.** As it stands today, this old bridge (Fig. 5) has three arches and a suspension span over the gap where other arches originally stood. The present bridge is on the site of **Pons Aemilius** (Fig. 6), built B. C. 178-142,

above Pons Sublicius and just below the island. The three remaining arches date from the time of Julius III., and are richly ornamented. Two arches were carried away by a flood in 1598 A. D., and have never been replaced. The bridge was unfortunately located for it has been swept out at least four times, the first time in the year 280 A. D. It was erected by Caius Flavius and is claimed by some authorities on ancient history, to be one of the first, if not the very first appearance of the arch in bridge construction. It has semicircular arches and a level roadway over the central portion, with end

Fig. 6.

arches shorter than the intermediate ones. It was called Pons Palatinus, Senators' Bridge and Pons Lapideus. In construction it is similar to the other old stone bridges of Rome, being built of peperino and tufa, faced with blocks of travertine anchored into the masonry. The parapets and spandrels are highly ornamented with carved panels, and each of the piers above the arches and foundations are penetrated with smaller arch openings. The panel work has disappeared from the

shore spans and the method of construction is plainly revealed. The arch ring is made of different material and is differently laid to the filling above it, and numerous openings appear in the backing, showing the method of anchoring the facing blocks to the body of the structure. A large amount of concrete was used in the construction of the Roman bridges and aqueducts. It is possible that when first built, the piers only were of stone with wooden floor.

Pons Probi (381-387 A. D. ?), which was the furthest bridge down stream, is thought by some to be the same as Pons Aemilius. It was partly burned in the eleventh century and completely in 1484, though the base of piles still remains.

(3) **Pons Milvius,** known also as **Ponte Molle,** carries the Flaminian Way over the Tiber about a mile and a half from Rome, and was probably built in the time of Sulla by censor Aelius Scaurus about 100 B. C. As the Flaminian Way was completed B. C. 220, it is possible that the bridge is of earlier origin. It has seven spans varying in length from 51 to 79 feet, and the total length of bridge was 413 feet. Its width is 28 feet 9 inches. Over the roadway were arches, placed there by Augustus in honor of himself, and notwithstanding numerous changes and restorations, including one in 1808, some parts of the original bridge still remain. The piers, as in other ancient Roman bridges, are pierced with minor arches. Over this bridge the conspirators associated with Catiline, fled in confusion.

(4.) **Pons Fabricius,** over the Tiber at Rome, later known as Ponte Quattro-Capi, was built 62 B. C. at the time of the Catiline conspiracy, by Lucius Fabricius, engineer of roads and bridges. As mention is made of wooden bridges to the island in 291 B. C., the stone structure may have been a reconstruction. It is 250 feet long and has two semicircular

80-foot arches with rings 6 feet thick. A 13-foot arch pierces each abutment and it has a similar 16-foot arch through the center pier, which is 33 feet thick. Like other bridges of Rome, it is said to have additional arches at the ends buried in the embankments. The bridge spans one channel of the Tiber to the island of Aesculapius and is a continuation of Pons Cestius over the other channel. It was originally of wood, but was reconstructed just before the Christian era (21 B. C.) of peperino and tufa faced with travertine. It

Fig. 7.

once had triumphal arches over the roadway, and is the only one of all the ancient bridges of Rome remaining complete and in use up to the present day. On a tablet beneath the parapet and on all the arch rings are historical inscriptions. (Fig. 7.)

(5.) **Pons Cestius,** or Gratianus, sometimes called Ponte-di-San Bartolomeo, originated 46 B. C., was several times rebuilt, the first time in A. D. 365, the third time in the eleventh century, and again in the years 1886-1889. Originally there were on the bridge two marble tablets with inscriptions, but in 1849 one of these was lost in the river when a portion of the bridge was removed by order of Garibaldi, to prevent soldiers from entering the city. It crossed the Tiber to the

island with one span of 76 feet, and a small opening at each side, being a continuation of Pons Fabricius.

(6.) The **bridge of St. Angelo** at Rome was built by Emperor Hadrian in the year A. D. 135 to connect Campus Martius with the Mausoleum which he erected for himself. The tomb is now generally known as the Castle of St. Angelo. The bridge crosses the Tiber and was originally known as Pons Aelius. It is said to have had a roof of bronze supported on forty columns, which was afterwards destroyed by the barbarians. Pope Nicholas III. made some restorations and others were added by Clement IX. in 1668, who embellished it with ten colossal statues of angels carved in white marble. The statues of Saint Peter and Saint Paul at the ends were erected in 1530 by Clement VII., taking the place of two chapels. The idea in placing figures of angels at either side was evidently to show that heavenly messengers welcomed pilgrims to the sacred shrine. Originally it had three main arches with two smaller ones on the right and three on the left, but two of the latter were buried in the bank and not discovered until the restoration of 1892. Only six arches are now visible, though three are enough for the river in dry seasons. The span of the largest is 62 feet and the smallest 26 feet, the width over parapets being 50 feet. Piers are 21½ feet thick and the roadway is 50 feet above low water. Excepting the parapets, the bridge is almost entirely ancient. The pedestal of one statue bears the impression of a cannon ball, made during the siege of Rome in 1849.

The remains of another old bridge (A. D. 60-64), which once carried **Via Triumphalis,** can be seen when the river is low, about 100 yards below the Bridge of St. Angelo. It has been called **Pons Neronianus,** and connected Campus Martius with the Gardens of Agrippa, the Circus of Nero and the Vatican meadows.

(7.) **Ponte Sisto** at Rome was constructed under Sixtus IV. in 1474 on the ruins of the old **Pons Janiculensis** crossing from Trastevere. The old Roman bridge Pons Valentinianus, or bridge of Valentinian I., is said to have occupied the same site, and been rebuilt A. D. 366. Other reports seem to show that Pons Aurelius stood on the site and was restored in the time of Hadrian. Still other records indicate that the site was once occupied by Pons Antonius. After a flood had destroyed part of the bridge in 772, it was renamed Pons Fractus. It crosses the Tiber with four semicircular arches and at either end are steps leading down from the street to the river. The deck has side extensions supported on pairs of heavy brackets at the piers, and the road is guarded with railings. An inscription on the bridge begs the prayers of travelers for its founders, and a fountain at one end was added by Paul V. Ruins of three or four rows of piers, found in 1889, 340 feet up stream from Ponte Sisto, indicate the probable site of some old bridge of which nothing is known, but which may be Pons Agrippae, A. D. 34.

(8.) **Pons Triumphalis,** or the Triumphal Bridge of the Caesars, sometimes called Pons Vaticanus, from its proximity to the Vatican, and Ponte Ferrato or Cestius Gallus Bridge, both over the Tiber at Rome, have disappeared, and only encumber the Tiber with their remains. When building the new Garibaldi bridge at Rome, remains of an old one having two 10-foot arches and a middle pier 7½ feet thick and 20 feet wide, were found in the Tiber and removed. It was probably built in the early years of the Roman republic.

Other Roman Bridges.

19. **Ponte di Nona,** near Gabii, Italy, built in the years 124-121 B. C., has seven stone arches of tufa and travertine, with a total length of 225 feet, and is still in use.

20. **Julius Caesar's bridge** over the Rhine (Fig. 8), 55

B. C., is said to have been built in ten days in the face of the enemy. It was a wooden trestle with sloping piles driven into the river bottom, supporting cross timbers which carried the floor joist. It was 1,800 feet long, 40 feet wide,

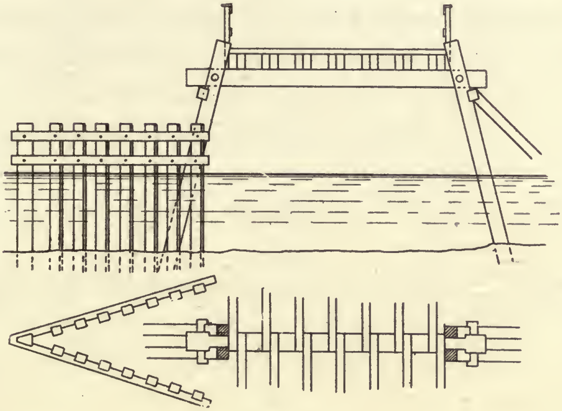


Fig. 8.

and contained about fifty spans, and the piers were protected with fender piles at the up-stream end. One historian states that it was located near Bonn, and others, between Coblenz and Andernach. It is fully described in Caesar's Commentaries.

21. The bridge at Narni, Italy, was considered the finest of all the Roman bridges. It was built by Caesar Augustus, over the Nera, between the years B. C. 27 and A. D. 14, and had four spans of 75, 135, 114 and 142 feet, respectively. Its total length was 367 feet, height 112 feet, width 75 feet. The stones were put together without cement, and history states that in 1676 only one span remained. Nothing is now left but the barest ruins.

all w 75 135 114 142 466

Other bridges of Augustus, of which only vestiges remain, were at Borghetto, Aosti and Calzi, while others by the same ruler at Verona and Vincenza, which were once destroyed,

have since been rebuilt. Ponte Felice, over the Tiber near Borghetto, had four spans, the end ones 51 feet long, and the middle ones 59 feet, between very heavy piers. It is said that the boast of Augustus was that "he found Rome a city of brick and left it a city of marble."

22. The old Roman bridge (Fig. 9) crossing the Marachia at **Rimini** (Ariminium), Italy, is supposed to have been built during the reign of Augustus. It has five arch spans with very heavy piers, and the details still remaining show that originally the bridge was very ornamental. Above the piers are panels formed by columns supporting entablatures, and

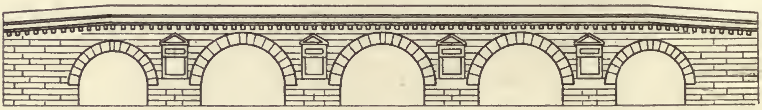


Fig. 9.

the heavy stone cornice is carried on numerous brackets. The arches are all semicircular, the end ones having spans of 23 feet, while the three intermediate ones are 28 feet. The stones in the arch ring are so finely jointed that they appear to have been ground together. At one time marble porticos stood above the roadway.

23. The remains of a very ancient structure known as **Caligula's Bridge"** has stood for centuries on the bay of Pozzuoli near Naples. It is thought to have extended across the bay to Baie with a length of about three miles, but there is much doubt as to its origin and date of construction, though generally believed to be the work of Caligula. (See Pontoon Bridges.)

24. A bridge over the Tagus river at **Alcantara** (Arabic word for bridge), near the border of Spain and Portugal, was built during the years A. D. 98 to 105, by Lacer, in honor of Emperor Trajan (Fig. 10). It contains six semicircular

granite arches of various spans, the largest being 115 feet, and has a total length of 670 Spanish feet. It was 26 feet wide and the roadway was 205 feet above the water, and it remained in use until A. D. 1809, when the second arch from the right bank was destroyed by the English army. Temporary repairs were made, but it was again destroyed by the Carlists in 1836 and has not since been restored. The stones

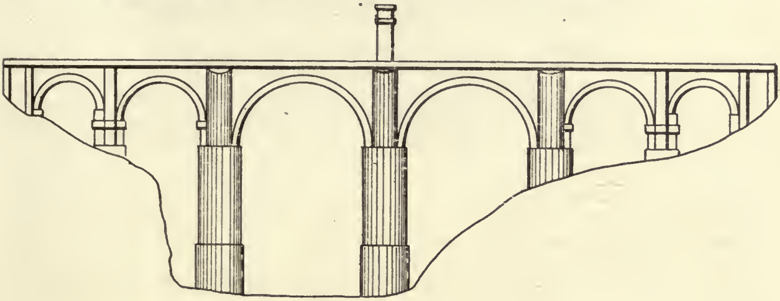


Fig. 10.

were put together without mortar, and it is said that originally triumphal arches stood above the roadway at the ends, but if so, they have long since disappeared. Only one of the river arches now remains, and this one compares favorably with bridges of the present day.

25. **Trajan's bridge,** over the Danube near Warkel in Hungary (Fig. 11), below the rapids of Iron Gate, was built A. D. 104 under the direction of Apollodorus of Damascus, who was the greatest engineer and architect of his time. The bridge was 150 feet high, 60 feet wide, and the length is variously reported at 3,900 to 4,500 feet. It was built to form a roadway over the Danube river for Trajan's soldiers during his warfare into Dacia, and was one of the earliest permanent war bridges, previous ones being constructed chiefly of boats or rough timber. It had twenty wooden arches of 170-foot span, supported on piers of squared stone, but was destroyed by Hadrian, A. D. 120, because of his jealousy of Apollodorus,

its builder. Remains of some piers are still visible, and foundation piles have occasionally been drawn from the river bed. Trajan's Column at Rome shows the bridge in bas relief, without dimensions, and there is doubt as to the actual form of

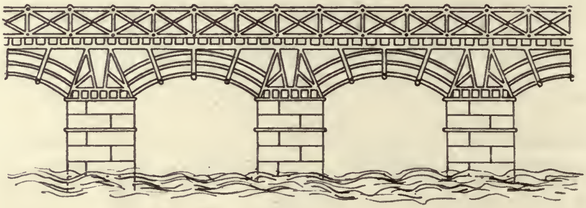


Fig. 11.

arch and length of span, as those on the Column may be merely suggestive and not to scale. The river at the site has a depth of 18 feet and the piers were built by sinking caissons.

26. **Ponte Salaro,** carrying the Salarian Way over the Anio or Teverone river, was built by Narses in the sixth cenutry A. D. It had a central arch of 87 feet 9 inches, and two small arches 14 feet wide in each abutment. The bridge was 27 feet 9 inches wide, and the height of the deck at the center was 50 feet above the springs. At one time a fortification tower stood at one end. The bridge was blown up by the inhabitants in 1867, to prevent the approach of Garibaldi to Rome. In its earliest state it has been attributed to Tarquinius Priscus about 600 B. C. The Roman bridge at Mostar, Bosnia, with slightly pointed arch and sloping roadway, is of unknown origin.

27. Pontoon bridges used by Alexander the Great, 330-327 B. C., Caligula's bridge, 40 A. D., and others of the Roman period, are described under Pontoon Bridges.

28. A timber arch with a platform suspended from it, which is probably the old bridge at Mayence, is clearly shown

on an old Roman medal. Wooden piles have been removed from river beds in Germany, where they have been for two thousand years or more.

29. A bridge over the **Guadiana** river at **Merida,** Spain, with 64 arches, and 3,900 feet long, is believed to be the work of Trajan. It bears Arabic inscriptions, and piers are made in Roman style suggesting its probable origin. Other Roman

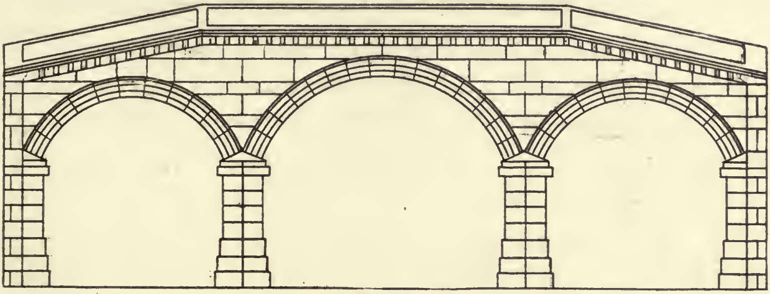


Fig. 12.

bridges in Spain attributed to Trajan, which have been well preserved by the Moors, are those at Alconeter, Almazar, Cuence, Chaves, Evora, Martorell, Orense, Olloniego, Salamanca and Ona. Pont de Martorell, over the Noya, with a center 124-foot span, and smaller arches at each side, is surmounted at the center with an enclosure, but the Salamanca

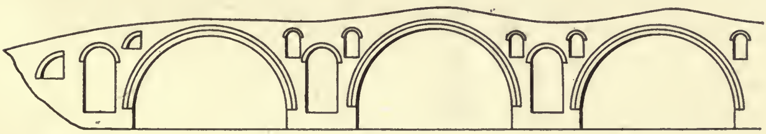
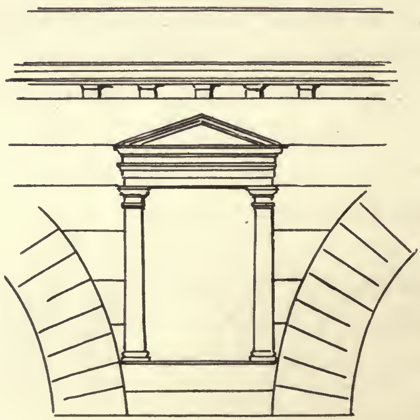


Fig. 13.

bridge is the finest one of all. The three-span arch bridge at Vicenza, with center and side openings of 69 and 55 feet, is also said to be of Roman origin (Fig. 12). A bridge over the **river Drin in western Turkey** (Fig. 13), on the road from Monaster to Sculari, still remains, after the lapse of cen-

turies. It has at least three main arches with long arched openings in the piers, and other minor arches through the spandrels. Its origin is uncertain, and while tradition attributes it to the Roman period, the treatment of piers and the spandrel arches are more oriental than Roman.

30. Many of the finest Roman bridges were those supporting aqueducts, some of which are still in an excellent state of preservation. These include no less than fourteen for the city of Rome, Pont du Gard at Nimes, France; Segovia and Tarragona in Spain; Alcantara in Portugal, and others at Antioch, Metz, and Bourgas near Constantinople. (See Aqueduct Bridges.)



RIMINI BRIDGE

CHAPTER III.

MEDIAEVAL BRIDGES. 500-1500 A. D.

31. Bridge building, like architecture and many arts, suffered a severe decline during the Dark Ages (500-1100 A. D.), following the fall of the Roman Empire, and was not revived again until the eleventh and twelfth centuries. Very few important bridges were built during these ages excepting those in Spain by the Moors, who were a careful and cultured race. The semicircular arch continued almost exclusively in use from its introduction before the Christian era, until the thirteenth century, when pointed arches reappeared, and elliptical and segmental forms were usual in the fourteenth century. In the 400 years (1100-1500 A. D.) following the Dark Ages, bridges were poorly and cheaply made, frequently not more than 6 or 8 feet in width, and seldom more than 20 feet. They often had steep grades at the ends, were inferior to those of the Romans, and frequently had unequal spans. The hostile condition of adjoining countries often made it necessary to provide means of protection, and fortification towers at the ends were a common feature.

32. A religious order under which much bridge building was done, was known as "**The Brothers of the Bridge**" founded in the twelfth century by Benedictine monks. The Order established houses at the river crossings for the comfort and safety of travelers and for protection against thieves and bandits, and the building and preservation of bridges became a sacred duty. The Brothers also raised money for building

bridges and sometimes superintended their construction. The director of this religious order was called the Pontifex Maximus, a title in the church of Rome to the present day.

French Mediaeval Bridges.

33. Among the bridges in France built during the Dark Ages (500-1000) were those at Vaison, Chateau Neuf and Saint Chamas, the last having triumphal Corinthian arches at the ends, mounted with figures of reclining lions. **Saint Chamas bridge** (Fig. 14) spans the Tolubre river with a clear span of 41 feet and a total length of 83 feet, the funds for

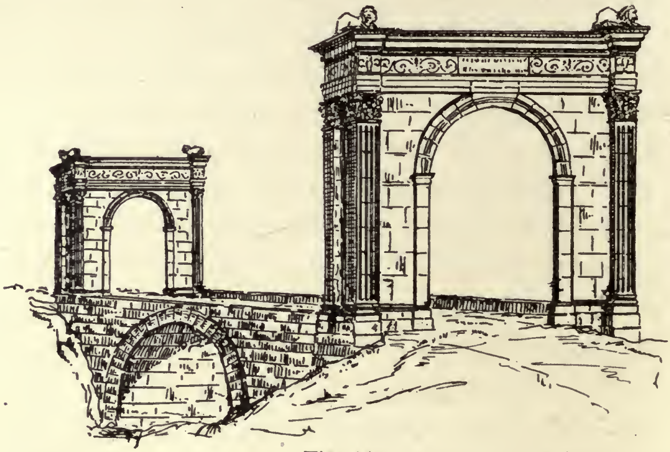


Fig. 14.

its construction being a private donation. Some writers consider the bridge to be of much earlier origin, dating back to the Roman period in the reign of Caesar Augustus (14 A. D.).

During the latter part of the eleventh century, bridges were built at Vienna, Tours, Orleans and Lyons. One of the earliest by the Brothers was that at **Maupas or Bonpas** over the river Danube, with towers at each end, but it was washed out soon after its completion.

34. The **bridge at Avignon** over the Rhone, in Southern France, was built 1178 to 1186 under the direction of Saint

Benezet, who was once a shepherd boy. Four pointed arches still remain, having a smaller radius of curvature at the crown than at the haunches. Money for building it was raised by a pretended miracle. It originally contained 22 spans, the longest 110 feet, and it had a clear width between parapets of 13 feet, a height of 46 feet, and a length of 2,000 feet. A chapel to Saint Nicholas, protector of those who travel on the river, originally stood on the third pier. The bridge was bowed up stream to better resist the force of the current. Some of the arches were destroyed in 1385 by Pope Boniface IX., and in 1410 a tower was blown up by the inhabitants, carrying down three spans with it. Several more spans were washed out in 1670. Other bridges built by the Brothers are those at Ceret, Nions, Saint Esprit and Villeneuve.

35. The bridge over the **Charente at Saintes** (Fig. 15) was probably built in the middle of the fourteenth century, though one historian attributes it to Isembert, the engineer who com-

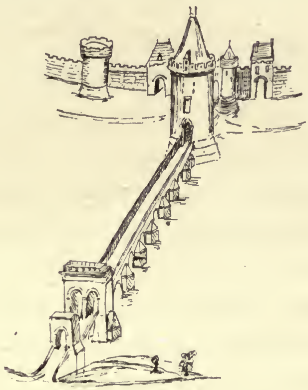


Fig. 15.

pleted old London bridge in 1209 after the death of Colechurch. Ornamental towers of different design rose high above the roadway on each side of the river at the low water line, while other smaller towers with gateways were erected at the ends.

The design of the towers at one end was made to conform in architectural treatment with the adjoining castle, while the main tower at the other end was a monumental Roman arch with two roadways. The part between the main river towers was divided into seven spans, while the end sections between the main towers and the entrance gates, was divided into three arch spans. The platforms of the three spans at each end were of wood, and were so arranged that they could easily be removed to obstruct travel in case of hostilities. The towers and gateways and their relative positions, make the bridge one of the finest early examples on record.

36. Thirty miles from Nimes in Southern France, a bridge was built over the Rhone at **Saint Esprit,** with 26 stone arches of various lengths from 81 to 114 feet. It is 18 feet wide, and 2,700 feet long, and the piers are 28 feet thick at the springs. The piers are pierced with smaller arches conforming with Roman practice, and the rapid current of the river at the site was doubtless due to some extent to the obstruction of the heavy piers. It was built from 1265 to 1309 A. D. by the Brothers of the Bridge, and for many years was the longest stone bridge in existence. Money for its construction was raised by voluntary offering.

37. Another bridge over the Rhone known as the **Guillotiers,** was built at Lyons in 1265 A. D. It had 18 spans of various lengths from 26 to 102 feet with piers 34 feet thick at the springs, and like the one at Saint Esprit, was under the direction of the Brothers. It was blown up in time of war, and for a long time remained in ruins.

38. **Pont Valentre** (Fig. 16), over the Lot at Cahors (1280) in Southern France, has six pointed arches and three towers for defense, one at each end and the other in the middle. Montauban also has a stone arch bridge of many spans, built 1303 to 1316, with slightly pointed arches, and Pont du Ceret,

over the Tech river near Perpignau, is a semicircular arch order are at Castellane over the Verdun river, with 90-foot span (1494) and one over the **Allier river** at **Brioude** (1454), with a semicircular span of 150 feet, a width of 16 feet and a height of 60 feet, by Estone and Greiner, engineers. The bridge of 147-foot span and 13 feet wide, built by the Brothers (1336). Other bridges built under the direction of this

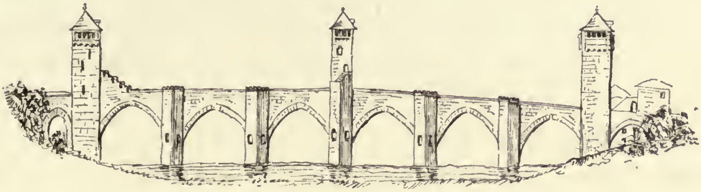


Fig. 16.

arch ring was very thin and was the only cut stone used, the rest of the masonry being rubble. The piers above high water were faced with cut stone but were filled inside with sand and gravel. It collapsed in 1822 and was soon afterwards rebuilt. Another bridge at the same place is attributed to the Romans.

39. The bridge at **Sisteron** over the Durance, with a single span of 65 feet, and the Notre Dame bridge at Paris, were both started in 1500. The Notre Dame bridge, still remaining, replaced one which fell in 1498, and was rebuilt with six spans of 56 feet and a width of 77 feet, but was not completed until 1507.

Other French bridges of the Middle Ages are the Roman Pont Sommieres, over the Virdoule, with a long series of 32-foot openings; Pont Albi (1035), with seven pointed arches and five houses balanced over the piers; Pont Carcassonne, over the Aude, with a series of 46-foot openings (1180); Orthez, over the Gave, with three or more spans and a central tower (thirteenth century); and a bridge over the Isere (fifteenth century), with a house over the first pier.

Italian Mediaeval Bridges.

40. From the decline of the Roman empire (500 A. D.) until the thirteenth century the Italians built many bridges of wood which have not endured like the stone ones of their predecessors, and records of which are not extant. With the general revival of art, marble began to appear as a structural material, and two of the most noted ones remaining are of this beautiful variety of limestone. A bridge by Narses in the sixth century, over the Teverone river, is a single semicircular span of 87 feet with a smaller arch in each abutment. The earliest structure at the site is attributed by some authorities to Tarquinius, about 600 B. C., and a fuller description is included under Roman Bridges.

41. The Serchio river bridge near the baths of Lucca, Italy known as one of the "Devil's Bridges," built prior to A. D. 1000, has one span of 120 feet and four smaller ones of 17 to 46 feet, and a roadway 68 feet above the water (Fig. 17). It is very narrow, being only 9 feet wide in the clear and 12 feet

Fig. 17.

outside, resembling a great wall more than a bridge. It has resisted several heavy floods, in one of which the water rose 30 feet above the springs. The grade of the roadway is very steep and difficult to ascend, and it is impassable for modern vehicles.

42. The Spoleto viaduct, according to Gauthey (Fig. 18), was built by Theodelapius 741 A. D. to carry an aqueduct across the valley. It has ten Gothic brick arches of 70-foot span on piers 11 feet thick, and the deck was 426 feet above the valley, being the highest stone bridge in the world. There is, however, some doubt about the account, as the viaduct

which now exists is quite different to this description. It is only 250 feet in height, and is believed to have been built in the thirteenth century, not by an emperor but by the munici-

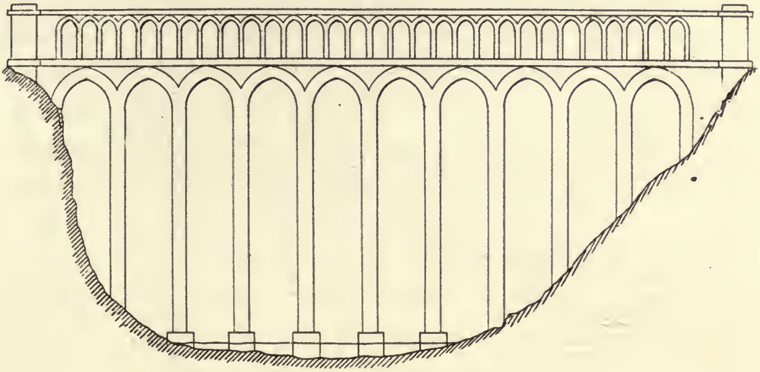


Fig. 18.

pality. The present piers are wider than the arches, and in several of the spans are intermediate braces at half the height above the valley, added at a later period.

Fig. 19.

43. **Ponte Vecchio,** over the Arno at Florence (Fig. 19), is the most important and interesting of the four old ones at that city. It was originally built in the year 1177, though some authorities state that it has existed since the Roman period, but was rebuilt by Neri di Fiorvante in 1345 A. D. The three segmental arch spans with lengths of 85 to 96 feet and a rise of 19 feet, carry rows of jewelers' shops on both sides, with an upper footwalk between them, the covered gallery forming a continuation of the passage between the Pitti and old Ducal Palaces. Its total width is 105 feet and the piers are 20 feet in thickness, the design having been executed by the architect Gaddi. There is another very plain single span arch bridge known as Ponte Vecchio at Calci near Pisa.

44. The **Verona bridge,** over the Adige river near Vieux-Chateau, was built in 1354 under Scala, and consists of three segmental arch spans of 146, 87 and 33 feet, respectively, with piers from 22 to 36 feet thick, and round battlemented towers at each end. The first permanent wooden bridge on the present site of the Rialto was erected in 1180 by Nicolo Barattiere, and in 1260 was replaced by another of wood, containing a small draw span. The bridge was intended both as a passage across the canal and a lounging place for citizens. Ponte della Paglia, Venice, near the southwest corner of the Ducal Palace, was completed in 1360, and is still a favorite assembling place for the inhabitants. The floor rises with steps like the Rialto, but has no shops or other enclosures. Ponte di Pietra, at Verona, was rebuilt in the fifteenth century by Fra Giocondo, the architect of the Notre Dame bridge at Paris. It replaced an old Roman bridge on the same site, the two arches at the left bank being the original Roman ones.

45. For centuries the **arch at Trezzo,** over the Adda river, was the longest masonry span ever attempted (Fig. 20). Its erection belongs to the latter half of the fourteenth century,

ing 87 feet above the springs. Two separate ring courses, the inner one being 3 feet 3 inches, and the outer one only 9 probably in the year 1380, and was ordered by Barnabo Viscounti, Duke of Milan. It was a single granite arch in two courses, with a span of 251 feet and a radius of 133 feet, ris-

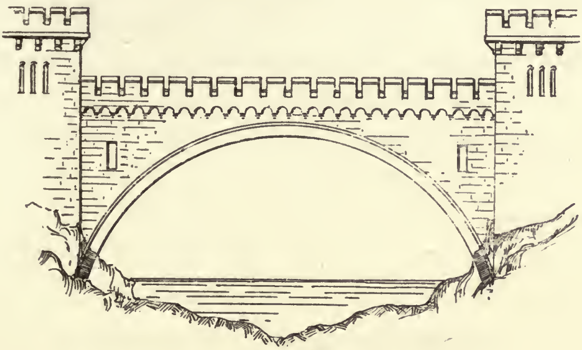


Fig. 20.

inches thick, made a total arch ring thickness of 4 feet. The bridge carried a highway, and, although fortified, was destroyed by Carmognola about 1410. In 1838 about 20 feet of each abutment arch still remained.

46. A bridge over the **Ticino at Pavia,** of very unusual design, was built in the fourteenth century under the direction of Galeas Viscounti, Duke of Milan. The seven pointed arches were of 70-foot span and 64-foot rise, with crown thickness of 5½ feet and pier thickness of 16 feet. The bridge proper was of brick and was covered by a roof supported on one hundred granite or marble columns. The original construction no longer exists, though the present one, with six arch spans, the largest 100 feet, is several centuries old.

47. Other bridges of the period are the Admiral bridge (1113) over the Oreto near Palermo, designed by George of Antioch, a bridge at Pavia over the Tess (thirteenth century) with several spans of 41 to 77 feet, and central deck towers,

and Alexandria bridge over the Tanaro (fourteenth century) with covered passageway on a series of arches from 54 to 68 feet. The bridge at **Torcello** is also interesting because of the stepped parapet following the grade of the roadway. In the year 1474 Ponte Sisto, over the Tiber at Rome, was rebuilt under Sixtus IV., on the ruins of the old Pons Janiculensis. The site is a historic one, for its was previously occupied by Pons Valentinianus. Bridges at Signa and Mossa probably belong to the fifteenth century.

Mediaeval Spanish Bridges.

48. Roman bridges were better preserved in Spain during the Dark Ages (500-1100 A. D.) than in any other country. The Moors, who were a cultured and educated people for their

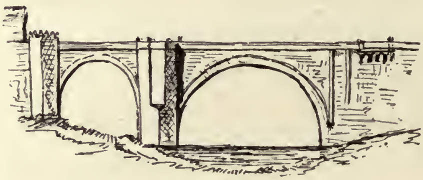


Fig. 21.

time, were careful of their public works and built some new bridges patterned after Roman ones, among which were those at Cordova and the Alcantara bridge at Toledo. The **Cordova bridge,** over the Guadalquiver river, has sixteen spans and was built in 916 by Saraceus, in the reign of Hesham or Is-

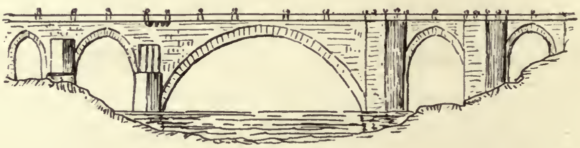


Fig. 22.

sem, the second Moorish king in Spain. The bridge of **Alcantara at Toledo,** Spain (Fig. 21), also by the Moors, has two semicircular arches of 50 and 93 feet, and was completed in

997. It has triumphal arches and is still in good condition. **St. Martin's bridge,** over the Tagus at Toledo (1203) (Fig. 22), has a central span of 132 feet with 38-foot span at each side, and a shorter one at each end. The central arch is very slightly pointed.

Other bridges of this period in Asia Minor are at Adana, Aspendon, Antioch, and Aleppo, the two latter having four and thirteen arches, respectively. A bridge at Beirut has seven arch spans, and another at Hamarth eleven spans. Some authorities have, however, attributed these six bridges to Trajan, A. D. 98-117.

Mediaeval Austrian and German Bridges.

49. Few records are available concerning any new bridges in Austria and Germany during the Dark Ages (500-1100). The first one of the period was over the Danube at **Ratisbon or Regensburg,** Bavaria, built by the Germans in 1135. The semicircular arches were fifteen in number, and 33 to 53 feet in span, and total length was 994 feet. Following this was the stone arch bridge at **Dresden** over the Elbe. It belongs to the period of Augustus II., between 1179 and 1260, and during 1727 to 1731 was widened by adding brackets to support sidewalks. It is believed to be the first stone arch bridge over the Elbe at Dresden. It is nearly one-quarter of a mile in length, 37 feet in width, and contains sixteen or eighteen semicircular arches of 34 to 55-foot span, supported on piers about 30 feet thick. Engineer Fotius directed the construction. During the war of 1813 it was partly destroyed by Marshal Davout. Fine fortification towers at the ends are notable features of both the Ratisbon and Dresden bridges.

50. The old **Holy Cross bridge** at Feldkirch, Austria, over the Ill river, of 1250, contained one semicircular arch of 60 feet and 11 feet wide, and was replaced in 1898. The old bridge

at Frankfort on the Main (1342), of red stone, supports a statue of Charlemagne, and near it an iron cross with a figure of Christ, surmounted by a cock. Charlemagne enacted laws for the preservation and protection of bridges and placed the care of them upon the local bishops, authorizing them to collect tolls and make necessary repairs. The bridge of Kosen over the Saale, erected in the thirteenth century, has pointed arches, eight in number, of 20 to 27 feet, with roadway inclining to the center.

At Berne, Switzerland, the first bridge over the Aar river, adjoining **Nydeck castle,** was built in 1204, with a span of 150½ feet.

51. The stone arch bridge over the Moselle river near its junction with the **Rhine at Coblenz,** was erected in 1344 by Elector Baldwin, and contains fourteen spans. It was repaired in 1440; in 1832 a tower was added; and in 1884 it was further rebuilt. In 1864, when the water in the river was very low, remains of an old Roman wooden pile bridge was discovered just below the site of the stone bridge, which remains are believed to date back to the fifth century.

52. A greater length of time was occupied in building the **Karlsbrucke,** over the Moldau at Prague (Fig. 23), than any other bridge in history. It was commenced by Emperor Charles IV. of Germany in 1348, but not completed until 1507, after a period of one hundred and forty-nine years. It has sixteen arch spans, the largest 69½ feet, and over the piers on either side are thirty statues and groups of saints. The total length is 1,855 feet, and at either end are gate towers with unsymmetrical roofs. Notwithstanding the unusually heavy piers and icebreakers, it was seriously damaged by flood in 1890 and since has been repaired. The large bronze statue was erected in memory of St. John Nepomuc, the patron saint of Bohemia, to visit which thousands of pilgrims come an-

nually. It is said that St. John had received confidential information from the Empress, and on refusing to betray the secrets, the Emperor caused him to be thrown from the bridge and drowned. It is further related that Emperor Ferdinand II., after defeating the Protestant Bohemian king, in the bat-

Fig. 23.

tle of White Mountain, near Prague, in 1620, caused twenty-seven Bohemian noblemen to be beheaded, and their heads hung in iron cages on the Karlsbrucke tower.

53. A bridge at Kreuznach, Germany, has at least three arch spans with large buildings balanced on the piers, presenting an unstable appearance; which one at Tournai, Belgium, has three pointed arches and heavy round towers with battlemented parapets at each end.

Mediaeval British Bridges.

54 The oldest stone bridge in Britain was one over the East Dart at **Dartmoor, England,** supported on three piers

made of large granite blocks. It is believed to date back two thousand years or more. The floor consists of granite slabs, some of which are 15 feet long and 6 feet wide.

55. **The Croyland bridge** (Fig. 24) is probably the most ancient arch bridge in the British Isles. This strange triangular structure which seems to be quite useless, crosses the Welland river at a point where it divides in two channels, known as the Nyne and Catwater rivers. The three pointed arches have their abutments at the angles of an equilateral triangle in three different counties, spanning the three streams, and forming separate roadways meeting at the center. Each of the semi arches has three stone ribs beneath it, and the grade of the floor is so steep that it is suitable for pedestrains

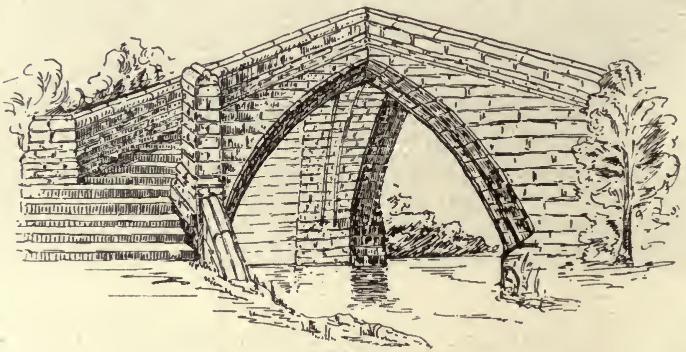


Fig. 24.

only. It is believed to have been first built about 860, as a charter referring to it is dated 943. The present structure has, however, indications of more recent origin and was probably rebuilt from the original design in 1380. At one end is an image, supposed to be that of King Ethelbald with a globe in the left hand and a crown on his head. The Abbot of Croyland, Lincolnshore, at the head of a religious order, probably directed the work. In 1854 the stream passing under it was arched over, and the surface is now dry.

56. A stone bridge at **Bow near Stratford**, England, was erected (1110 to 1118) over the river Lea, by order of Queen Matilda, wife of Henry I., but was replaced in 1835 to 1839 by a stone arch of 66-foot span. It is the earliest stone bridge in England of which definite records remain. For better resisting the force of the current it was bowed up stream, and was the first curved bridge on the island. Lives are said to have been lost in crossing the ford, and as the Queen had herself been in peril there, she ordered this bridge and another at Channelsea, to be erected.

57. An old Thames bridge at London is believed to have existed A. D. 978, though the first authentic records refer to

Fig. 25.

one of 1014, which was partly destroyed by fire in 1136. The old London bridge with shops on either side (Fig. 25), was started in 1176 by Peter of Colechurch, the same year that St.

Benezet began the Avignon bridge in France, but it was not completed until 1209. Peter is supposed have belonged to the religious order known as The Brothers of The Bridge, who built and raised funds for building bridges throughout Europe. He died in 1205 before the work was completed, and his remains were buried in a crypt of the chapel on the center pier according to the rules and customs of the society. After his death King John appointed as his successor, one Isembert, a French engineer who formerly directed the building of the Saintes and La Rochelle bridges. This bridge contained nineteen or twenty pointed arches with spans of 9 to 20 feet and a single draw span. Like other bridges of the time, it had defense towers, and on them were often hung the heads of decapitated traitors. The piers were 25 to 34 feet thick, founded on elm piles overlaid with plank, and occupied two-thirds of the whole waterway, with an enormous surplus of material, forming a serious and dangerous obstruction in the river . The total length of the bridge was 940 feet, but the clear space between the piers was only 310 feet. In 1212, three years after its completion, fire broke out at the south end and great crowds of spectators gathered on the bridge. Another fire then started among the houses at the north end, and people on the bridge were locked in between two fires and three thousand or more were drowned or burned. It was rebuilt in 1300, but was again burned in 1471, and again in 1632. The outside width did not exceed 40 feet and buildings often projected far over the water. In 1481 a whole block of these overhanging houses became loosened and fell over into the river. Up to this time the passageway between the shops or houses had been only 12 to 14 feet, and was hardly sufficient for vehicles to pass. Therefore in 1666, when the houses were again burned, they were rebuilt with a passageway of 20 feet. Another fire occurred in 1725, and in 1756 all houses

were removed and the middle pier and two arches replaced with a 72-foot span. Toll charges were discontinued in 1782, but it remained the only bridge across the Thames at London until the completion of the Westminster bridge in 1750, notwithstanding its excessive repair and maintenance cost of about $20,000 per year.

The tolls and offerings made at this and other bridges, were for their maintenance and repair, and had these offerings been honestly collected and carefully disbursed, decay in many cases would have been avoided. But as the management of bridges was frequently given to court favorites, the receipts were too often appropriated for private use.

58. A bridge, probably of the twelfth century, located at **Burton in Staffordshire** over the river Trent, has thirty-six arches of squared freestone, and a total length of 1,545 feet, being the longest in England. Originally it was erected by a religious order under Abbot Bernard, but was replaced in 1864. A bridge was also built at Norwich in 1295.

Two very interesting bridges in Scotland are "**The Bridge o' Balgownie**" and the "**Auld Brig o' Ayr.**" The first is a single Gothic arch of 67 feet crossing the river Don near Aberdeen, and its erection is attributed to Bishop Cheyne, in

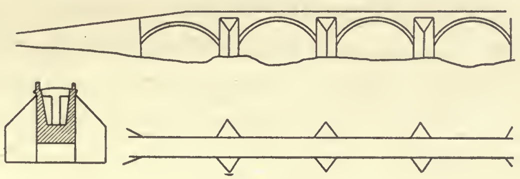


Fig. 26.

the year 1281. A stone bridge at Newcastle-on-Tyne is also recorded in the same year. The **Auld Brig o' Ayr** (Fig. 26) was of an earlier date, and is at least 700 years old, for it is referred to in a charter of 1236. The four segmental arches of 53-foot span and 18-foot rise, are borne on piers 15 feet thick with

long pointed cutwaters, the whole being founded on a grillage of oak logs a few feet below the surface. It has recently been restored by underpinning the piers and adding new concrete spandrel walls. The 12-foot roadway was so narrow that a new and more commodious bridge was erected close to it. It is one of the best known of the old bridges of Britain, having been immortalized by the poet Robert Burns.

59. Another old bridge of ten spans was built at **Rochester, England,** over the Medway about 1200, with piers 43 feet apart on centers, the openings between them being spanned with three lines of beams covered with plank. At the east end was a wooden tower for defense, but both tower and bridge were burned in 1264 by Simon Montford, Earl of Leicester. It was afterwards rebuilt in stone (1394) chiefly at the expense of Robert Knolles and Baron de Cobham, and is referred to during the reign of King Richard II. In order to raise money for repairing it, John Morton, Archbishop of Canterbury (1489), gave remissions to persons contributing for this purpose. Other bridges of the thirteenth century in Scotland crossed the Tay at Perth; the Esk at Brechin; the Dee at Kincarden and the Clyde at Glasgow (1345). The old **Forth bridge at Stirling** (1400) has at least four arch spans of about 53 feet and small towers at one end. Near it was fought the battle of Stirling in 1297. The Bishop Auckland bridge (1388) carrying a highway over the river Wear, has one 100-foot span with 22-foot rise, and one 91-foot span with 20-foot rise, and was the first segmental arch in England.

Mediaeval Oriental Bridges.

60. Records of engineering and architecture in China, Japan and other countries of the Orient, have not been well preserved and dates are not generally available. Recent travel in those lands show that bridges of fifty arch spans exist, and smaller ones with five to seven spans or less are very numer-

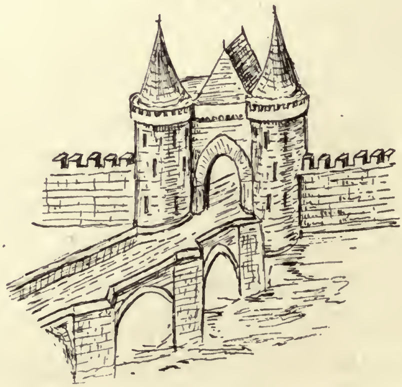
ous. The early engineers generally made their bridges with an uneven number of openings. Some single spans are, however, carried to heights out of good proportion, but made necessary for the passage of boats with sails. The city of Soochow, in China, has thirty miles of canals, crossed two hundred times or more with stone bridges. Bronze and marble bridges were common in China in the eighth century of our era. History reports the existence of a bridge over the **Laffranyi** river between two mountains, with a single 600-foot semicircular arch of white marble, 750 feet above the water. It was called the **"Flying Bridge"** and was built of blocks 7 to 12 feet in length. In the province of **Fo-Kien,** was another bridge 11,880 feet long (180 chains) and 25 feet wide with three hundred and one arches on three hundred rows of pillars. There were parapets at each side, and at intervals were figures of lions and other sculptures. Another similar structure is reported at **Fechew,** the capital of Fo-Kien, which is 4,950 feet long with one hundred lofty arches. It, too, has parapets ornamented with figures of lions, and is believed to be many ages old. The material in both these is fine hard white stone. **Loyong bridge,** five miles long over an arm of the China Sea, has three hundred stone arches, 70 feet high and 70 feet broad, and each pillar supports a marble lion 21 feet in length. Other bridges of remarkable proportions are reported at Focheu with a length of 22,000 feet and width of 60 to 70 feet.

61 A curious cantilever at the sacred city of Nikko, Japan, which is known as **"Shogun's Bridge"** was erected 500 or 600 A. D. It is described as follows: "The abutments are of hewn stone, the shore piers of hewn granite, octagonal and monolithic, mortised for stone girders. Monolithic plate beams receive the wooden structure. The stringers which fasten into the abutments balance over the stone beams, but do not reach by a considerable distance, the gap being fitted by mid-

dle stringers let into the stone stringers. It is not used by the laity." At Osaka, Japan, there are said to be 7,000 bridges over rivers and canals.

62. Three bridges at Adabazar, Adana and Mopsuestia in Asia Minor are believed to be the work of Justinian (A. D. 527-565). The one at Adabazar has eight arches of 75 feet each and a total length of 1,400 feet, while the Adana bridge in Cilicia has eighteen arches on very heavy piers, and the Mopsuestia has nine arches.

There are several bridges in Persia belonging to this period. Krast-Nemoust of the eleventh century is very plain with four arches of unequal span, the largest being 98 feet between piers with stone ice breakers. In Northern Persia is a very simple bridge in the village of Erivan (12th century) with two spans of 46 feet, and a smaller span at each end, the roadway being 20 feet wide. It was restored in 1830. The Doktare-Pol crosses the Kisilousou river near Tauris with three equal spans, and also belongs to the twelfth century.



CHAPTER IV.

THE RENAISSANCE PERIOD (A. D. 1500-1750).

French Bridges.

63. During the 250 years following A. D. 1500, bridge building was more active in France than in any other country and was chiefly under the direction of the Brothers of the Bridges or Pontifeces until the seventeenth century. The tendency was to make piers much thinner than formerly, and during the sixteenth and seventeeth centuries they were generally one-quarter of the clear opening, or one-fifth of the distance between pier centers. The use of elliptical and other flat arch forms commenced in France towards the close of the seventeenth century, the form resulting from the need of wider spans without excessive rise or too steep a roadway grade. A brick arch bridge at **Toulouse** over the Garonne river (1543-1632) containing seven spans from 45 to 113 feet and 64 feet wide, was very ornamental and a fine bridge for the time, A stone bridge at **Tournon** over the Doux river (1545) had one span of 157 feet, while the bridge of Chenonceaux (1556) supported the chateau with its three stories and many towers on a series of seven arches over the river. But the most important new bridge of the whole period was **Pont Neuf** over the river Seine at Paris. It crosses the end of an island, which divides the bridge in two sections. One of these sections has seven spans from 46 to 62 feet and the other has five spans in lengths of 31 to 48 feet. The construction was started in 1575, but was delayed by war until 1602, and was not completed till 1606. The width over parapets is 72 feet and the piers have heavy triangular cutwaters extending up to high water or a

little above the springs. From the cutwaters to the cornice are semicircular stone columns of the same width as the piers, supporting at the deck, lookouts or sidewalk retreats which are provided with stone seats. The bridge has a solid balustrade with two lamp posts at each side over the piers and a heavy cornice supported on stone brackets. On the island between the two sections is an equestrain statue of Henry IV. enclosed by an iron railing. The bridge was designed by Androuet du Cerceau, but was remodeled in 1853 by placing elliptical arches under the circular ones. Its total length is now 1,080 feet.

64. **The Claix bridge** over the Drac river near Grenoble in France, with a single span of 150 feet and width of 20 feet, was completed in 1611, but as it was narrow and the grade steep, a new stone bridge with a flat arch of 170 was placed beside it in 1874. **Pont St. Michael** in Paris, originally completed in 1617 was rebuilt in 1859, the number of spans being reduced and the width increased. Four other bridges over the Seine at Paris are Pont au Change (1639-47), Pont Tournelle (1656), Pont Marie (1635-58), and Pont Royal (1685). **Pont au Change** had seven short semi-circular spans of 35 to 51 feet, but was rebuilt in 1858 with fewer spans and greater width. **Pont Tournelle,** designed by Marie, has six spans of 45 to 59 feet, and was 53 feet wide. It was widened in 1845 by the addition of cast iron arches. The next bridge, known as Pont Marie from its designer, had five semicircular spans of the same length as the one previously designed by him, but was 77 feet wide. **Pont Royal** was designed by Mansard with five longer elliptical arches from 68 to 76 feet and piers 15 feet thick at the springs. St. Michael, Marie and au Change bridges still exist. The Cognet bridge over the Drac river at Hautes Alpes, France, with two semi-circular arch spans of 85 feet was only 11 feet wide. An ancient bridge of uncertain date over the

river Vienne at Limoges has seven or more pointed arches of uncouth design with heavy projecting round ended piers extending up to the parapet.

65. The dredging machine was used for the first time in building the foundations of a bridge at Maastricht over the Maas river in Holland, begun in 1635 under the direction of the Dominican monk, Romano. The use of flat vaulted arches in France began about the close of the seventeenth century.

66. At the beginning of the eighteenth century, it became evident in France that the public bridges, after centuries of neglect were in a dangerous condition and many of them must be rebuilt. The French Government therefore, in 1715, created a **department of Bridges and Roads** with M. Gabriel as chief engineer. This was the real beginning of the modern revival of bridge building in Europe. The movement was afterwards promoted by the establishment of an **Engineering School** in 1747, which was reorganized and enlarged in 1760 under the direction of **Perronet.** Under the new department of Bridges and Roads, development in bridge building was rapid. Elliptical and segmental arches of longer spans with slender piers were used and greater attention given to their architectural treatment. Piers were thinner than before, the usual thickness being one-fifth of the clear opening. But progress was sometimes accompanied with failure, for a three-span bridge at Moulins over the Allier river by Mansard (1705) with center and side spans of 147 and 115 feet, and piers 36 feet thick at the springs, collapsed in 1710. The Blois bridge over the Loire was built by Pitron in 1723 under the direction of Gabriel, having eleven elliptical arch spans of 54 to 68 feet, with a spire like finial on the balustrade to mark the center. Piers were 22½ feet thick at the springs, temporary centers being supported at the ends only, without intermediate blocking. Other bridges were built in 1732 at Tetes over the Durance, at Villeneuve

over the Lot and in 1740, one at Charmes over the Moselle.

Spanish Bridges.

67. **The Ronda viaduct** (Fig. 27) of the seventeenth century, is the principal one of the period in Spain. It is 460 feet high and 280 feet long on top, with a central opening 46 feet wide extending from the water nearly to the deck, the opening

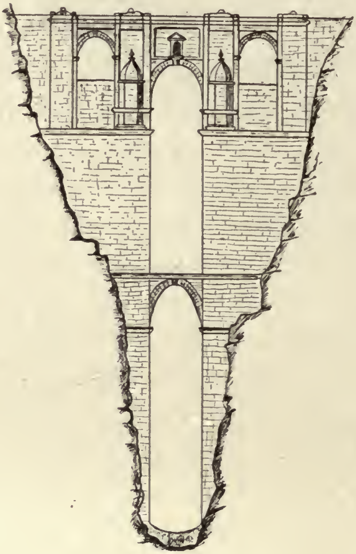


Fig. 27.

being crossed by an intermediate arch 230 feet above the bottom. At each side of the center opening is a 35-foot arch, and the piers between them are highly ornamented. The aqueduct of Alcantara at Lisbon (1774) is described in the chapter on Aqueducts.

Italian Bridges.

68. Italy made less progress in bridge building during this period than France, but it produced at least three of historic interest, Trinity bridge at Florence and the Riaito and Bridge of Sighs in Venice. A development of greater importance than the mere construction of a bridge was the discovery in 1560

by Palladio, an Italian architect, of the principle of the truss. It was first used in roofs and smaller edifices, but at a later period revolutionized the art of bridge building by making it possible to design trusses in iron and steel. Palladio was proficient in design, but unfortunately much of his finest work was never executed. A bridge at Munster on the Navante formerly in one span, was much superior to the Rialto. Another which was one of his grandest conceptions is described as containing several streets, "not for vehicles, but of lodges and porticos with statues of marble and bronze." **Ponte Curvo** over the Metza (1505) is a fine production with seven spans 74 to 94 feet in length, with a rising grade towards the center, and the bridge of Capodarso over the Imera, Sicily (1553), has a single span of 95 feet. **Trinity bridge** over the Arno at Florence, made of white marble, has three arches, the intrados of each being approximately a semi-ellipse, but really two parabolic curves meeting at the center, the Gothic center being covered with an ornamental shield. It was built in 1569 from a design by B. Ammanati, and has spans of 95 feet with a rise of 15 feet, or one-sixth the opening. The piers are 26 feet thick, and the width of deck is 33.7 feet, while the arch ring has a crown thickness of 2.75 feet. The clear water way between the piers is 270 feet and the total length 322 feet. At the corners are four allegorical statues representing the seasons. It is known in Italy as Pont della Santissima Trinita, and is believed to be the earliest bridge with flat elliptical intrados. Ponte Nuovo at Pisa is very ornamental and similar to Trinity.

69. The **Bridge of Sighs** between the Ducal Palace and prison in Venice was designed by Antonio da Ponte and completed in 1597. It crosses the Rio della Paglia, 32 feet above the water. It is enclosed on the sides, arched overhead, and provided with a partition down the center, forming two sepa-

rate passages. The bridge is small and contains little of interest apart from its historic association. A more important one is the Rialto over the Grand Canal, designed by the same architect as the last one. **The Rialto** (Fig. 28) is probably the best known bridge in Europe, and was built during the years 1588 to 1591. There is little doubt but that Michael Angelo prepared plans for it, and it is therefore often accredited to him. The Encyclopaedia Britannica in commenting on the subject says, "Erroneous statements have often been made that

Fig. 28.

this bridge was built from a design by Michael Angelo. The mistake has arisen from the misinterpretation of a passage in the works of Vasari." Michael Angelo believed that a bridge should be built as though it were intended for a cathedral, with the same care and of the same materials. Along with other Italian architects, he had a preference for marble over other building stones. The bridge has an extreme length of 158 feet, and a width of 72 feet. On the roadway are two rows of shops with a passage way between them, six shops in each row on either side of the center, or twenty-four in all. In the center of the bridge is an open passage connecting the roadway with the walks, the whole arrangement forming an

arcade. The footwalks on the outside are carried on projecting brackets, and as the floor grade is steep, the walks are provided with marble steps and enclosed with ornamental balustrades of beautiful design. The intrados is segmental, about one-third of a circle, and the arch ring and spandrels are ornamented on the face with figures of angels, and tablets with inscriptions. The material is white marble. Steps at either end lead up from walks along the canal, and the arrangement of arcades on the rising grade, together with the central passageway and the arch above, all present a general effect both pleasing and harmonious. At this time Venice is said to have had no less than three hundred and fifty-seven bridges. Wheeled vehicles were not generally used in Venice, and the bridges were almost exclusively for pedestrain travel, and yet none were neglected or allowed to fall into decay. **The Fleischbrucke** over the Regnitz at Nuremburg, somtimes called Pont des Boucheries, or Executioners' Bridge, was built in 1599 by Peter Carl and was plainly modeled after the Rialto in Venice. It is 53 feet wide, has a single arch of 97 feet, remarkable at that time for its flat curve, the rise being only 13 feet. It is founded on obliquely driven piles. Ponte di Mezzo (1660) with three spans, the center and side ones being 78 and 68 feet respectively, has flat segmental arches and heavy piers. Some other Italian bridges were remodeled during this period, among them the bridge of St. Angelo at Rome.

German Bridges.

70. A few new stone bridges appeared in Germany and Holland during this period, including one at Prague over the Moldau (1660), the bridge of Livettan near Torgan with a series of opening 46 to 49 feet long, and cut waters on alternate piers, the Meuse bridge at Maestrich (1683) and the Kurfursten bridge at Berlin (1695). The Prague bridge was 820 feet long with a series of 77-foot openings. The Kurfursten

bridge like others in Berlin is very ornate, but its principal feature is the central arch which is wider than the rest of the bridge. This extra width is carried down to the foundations with an offset at the two central piers, and the greater width on the deck is partly occupied by statuary.

British Bridges

71. Spanning the river Ross at Ross, England, is the **Wilton bridge** with five arches supported on wide piers with triangular cutwaters. It was built in 1590, but in 1644 the arch nearest the town was broken down by Colonel Rudhall to impede the advance of Colonel Massie's forces. On the north wall of the parapet is a quadrangular stone with a sun dial on each side. A stone bridge over the **Ouse at York,** England, erected during the reign of Queen Elizabeth (1558-1603), has five pointed arches, the largest being 81 feet. At one end was a house and clock tower, but the whole bridge has since been removed. **The Dorchester bridge,** with five or more pointed arches of unequal length and triangular cut-waters extending up to the deck, is interesting and very old. The bridge at **Llanrwst, Wales,** over the Conway river, was designed by Inigo Jones in 1634. Of its three spans, the center one was 58 feet, and as it vibrated easily, was known as the "shaking bridge."

72. Previous to opening the Westminster bridge in 1750, the Thames was crossed at only one other place in London. The word "bridge" as found in descriptions of London and the Thames, often refers to landing piers on the river, and this improper use of the word has given rise to some misunderstanding. An effort was made in 1671 to erect another over the Thames at Putney, but like similar projects, met with very serious opposition. One member of the London Council declared that another bridge would turn traffic away from the city and bring ruin to London, though the old one was not

wide enough for two carts to pass. **Westminster bridge** was begun by Labelye in 1738 and completed in 1750. It was 44 feet wide and contained fifteen semicircular stone arches, the longest or center one having a span of 76 feet, while the succeeding ones on each side decreased continuously by 4 feet, excepting the two end arches which were 25 feet each. Its total length was 1,164 feet, the arches having an aggregate opening of 820 feet, but they have since been replaced by cast iron. It marked the beginning of a new era in bridge foundations, for the piers were built with caissons instead of cofferdams, this being the first application of the new method. The caissons were sunk on a pile foundation, covered with timber. The cost of Westminster bridge was $1,120,000. A wooden arch bridge with stone piers, designed by John King, was being erected at the site and the stone piers were approaching completion, when Labelye in 1739, published a pamphlet stating the merits of his stone arch design and showing that Mr. King's plan could still be changed to give the city a permanent stone bridge instead of a wooden one, which latter he declared would be a disgrace to London. Labelye's efforts prevailed and after the city had paid the contractor a liberal sum to relinquish his wooden bridge contract, the plans were changed and the bridge completed in stone.

73. The **Tay bridge at Aberfeldy,** Scotland, was built in 1733 with one central arch and four smaller ones, two at each side. Four obelisks rise from the parapet at the ends of the main span, and over the center span is a tablet engraved with cross, crown, swords and the initials of King George. A mounment was erected at one end in 1887 to commemorate the raising of the Black Watch Regiment which was first mustered there in 1740. The bridge Bettws-y-Coed in Wales, is said by some historians to be of Roman origin. **Pont-y-Pridd,** near the town of Newbridge, Wales, crosses the river Taff with a

single 150-foot stone arch with a rise of 35 feet. The grade was one in four and was so steep that wagons had difficulty in ascending. It was 14 feet 5 inches wide at the soffit, increasing by six offsets to 15 feet 10 inches at the springs, and the roadway was 11 feet clear width at the center. The arch ring on the face was of cut stone 2 feet 6 inches thick at the crown, but the remainder of the ring, rubble masonry. The first bridge on the site was a three span arch built by William Edwards in 1746, and soon afterwards washed out, but as Mr. Edwards had given security for a seven year's guarantee he was obliged to rebuild it. The second bridge failed by rising at the crown, due to excessive weight in the haunches, and at the suggestion of the English engineer, Smeaton, when rebuilding it in 1750, it was lightened by coring out large circular holes in the masonry and using charcoal for spandrel filling. The designer and builder, William Edwards, was a village stone mason who had formerly been a clergyman for forty years. The first **Essex bridge** at Dublin was founded 1676 by Sir Humphrey Jarvis, but was taken down and rebuilt in 1753. Arran bridge in the same city, erected in 1684, was replaced in 1763 by Queen's bridge.

American Bridges.

74. The most notable bridge of the period in North America was the **Tempoalo aqueduct-viaduct,** built 1553 to 1570, seven miles south of Huauchinango, Mexico. It was erected by Tembleque under the direction of Franciscan friars and had sixty-eight semicircular stone arches, the largest being 58 feet. It lies on two connecting tangents containing an angle of 170 degrees, the maximum height being 124 feet and the water duct very small, only 8½ by 12 inches. Other similar aqueduct viaducts in Mexico are at Cuernavaca and Orizaba, while ruins of an ancient one are found at Acambarro, Mexico. An interesting old bridge at Santiago, Chili, croses the Mapocho

river on eight or more arches, the piers having round ends extending above the roadway at each side in the form of towers. At Callao, Peru, a stone bridge of four arch spans or more has heavy piers with round ends extending up to the parapet, and one at Arequipa, Peru, has similar piers extending to the roadway on each side of the center span, while the semicircular cutwaters of the other piers terminate below the arch springs. Other old stone bridges of uncertain date are found at Quito, Ecuador. Interesting ones in Colombia are Comun bridge with five stone arches; the Colon bridge, Bogota, with two stone arches, and the San Francisco, Bogota, with a single pointed arch.

75. In 1668, the **Great Bridge** at Boston, Mass., was built on the present site of North Harvard street bridge. This wooden pile structure was considered an important one at the time, for the population of Boston did not exceed three thousand, and the surrounding district was required to pay a portion of its cost.

Oriental Bridges.

76. A five-span wooden arch bridge designed by the Daimio, was placed over the **Kintai river at Iwakuni, on the** Isle of Honda, Japan, in the year 1673 (Fig. 29). Each of

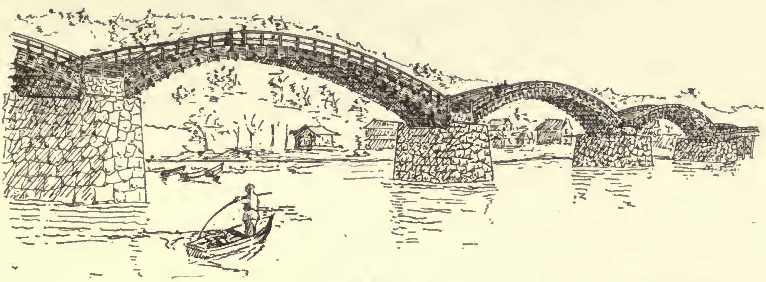


Fig. 29.

the three central arches is 149 feet, the total length being 745 feet and the roadway 18 feet wide. The piers are 37 feet high and their clear height beneath the center span is

71 feet. The arch ribs are made of keaki wood, which has high working strength, while the covering and balustrade is hinoki wood, a species of cypress. In ancient times, one of the spans was replaced every five years, to the whole bridge was rebuilt four times every century. As the floor follows the curve of the arches, it is evidently suitable for pedestrians only, and is built with treads and risers, the width of treads being uniform. Some of the stones in the piers were fastened with metal dowels and others cemented together with lead.

77. Persian bridges are very interesting, and picturesque and some of the later ones, elegant with rich ornamentation. characteristic of both East Indian and Moorish architecture. The arches are pointed (or ogival), the piers very thick, and brick is chiefly used in the construction. Of the earlier ones in this period may be mentioned Mianeh (1580) with twenty-three arches, and Tauris, constructed in 1610, with eighteen arches in a sinuous course across the river similar to Shuster bridge, and over 500 feet long. The ancient capital of Persia is Ispahan and in it are several beautiful bridges over the Senerud river, built during the reign of Shah Abbas the Great (1585-1628). One of these is described as being "2,250 feet long, 120 feet high and 156 feet broad with the center roadway of 60 feet. It has twenty-nine Moorish arches of 50-foot span with piers 25 feet thick. The sidewalks, which are paved with marble, are through elevated covered arcades which are reached by stairways in the four towers and supported by arches, three of which stand over each of the main fifty arches beneath. It is sometimes known as the **bridge of Barbaruh.**"

The bridge of **Allah-Verdi-Kahn** is named for the general who bore the expense of its construction. Its thirty-six freestone arches of 18-foot span carry the deck, the entire length of which is nearly 1,000 feet and 45 feet in width, and the

whole is elaborately decorated. It has a level roadway with galleries 10 feet wide on either side over the whole length of the bridge, raised several steps above the roadway. The gallery walks are supplied with frequent openings to admit light and air and give a river view, and there are open passageways above the galleries. The bridge of **Hassan-Bey,** which is about 415 feet in length and about 40 feet wide, is similar to that of Allah-Verdi-Kahn, but has a prominent central feature of added height and octagonal plan. The galleries with prominades supply a place of recreation for the inhabitants away from the heat of the city. The balustrades, spandrels and other parts of these bridges are treated in the highly decorative manner, with mosaics of stone and tiles in color, characteristic of oriental work.

78. The single stone arch bridge of El Ghajar crosses a stream which is one of the chief sources of the Jordan. The covered bridge of shops at **Srinagar, India** (Fig. 30), is supported on a series of large wooden cribs which occupy about

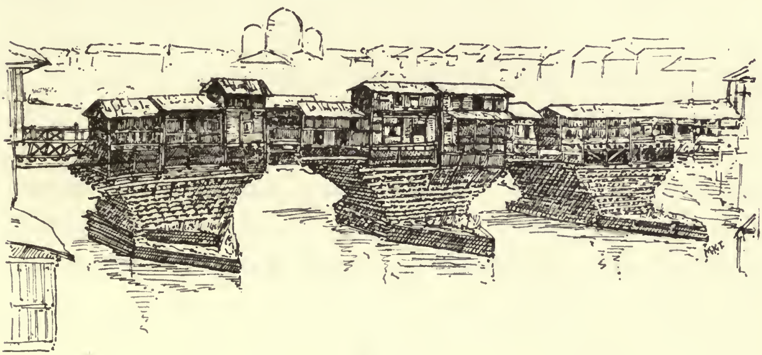


Fig. 30.

half the river width. The piers are protected with cutwaters up to high water, and the timbers are corbeled out at the top until they nearly meet at the center. The deck of the bridge is covered with a number of separate rustic buildings of various form and sides, and altogether, it is a unique production.

CHAPTER V.

MODERN STONE BRIDGES (1750-1900).

79. The revival of stone bridge building began in France about the middle of the eighteenth century, and many of the finest ones of the period are found in that country. In England, only one bridge spanned the Thames at London previous to the new Westminster bridge in 1750, and excepting the Blackfriars, most modern ones were not commenced until after the beginning of the nineteenth century. Prior to 1830, bridges were chiefly for highways and aqueducts, but with the building of railroads, came the use of many stone and brick viaducts in France, England and Germany, this form being the accepted type for thirty years, until quite generally supplanted by those of iron and steel. In America stone bridges were not extensively used prior to 1880, excepting for a few aqueducts, but since that date both stone and concrete bridges have been adopted by many American railroads. The commercial activity and prosperous conditions of the nineteenth century have brought masonry bridges more into use as permanent structures for American cities, and not only large city bridges but also smaller ornamental ones in city parks are made of the more durable material. The number of stone bridges built in all countries during the last one hundred and fifty years is therefore so great, that it is impracticable to tabulate or describe more than a few of the more important ones, the majority of those referred to having spans exceeding 50 feet. Long spans are not, however numerous, and in 1885 there were less than sixty brick or stone arch bridges with spans

exceeding 120 feet. Of these, twenty-seven were in France, thirteen in Italy, ten in England, two in Spain, two in Austria and one each in Switzerland, Germany and the United States; thirty carrying highways and twenty-two railroads. One had a span exceeding 214 feet; three, spans of 214 to 187; ten had spans of 187 to 152, and forty, spans of 152 to 120.

French Bridges.

80. France and England have been the leading nations in building masonry bridges since 1750. This was due in France chiefly to the government supervision of bridges by the department of Bridges and Roads created in 1715, and to the establishment and reorganization of an engineering school in 1760 under the direction of Jean Rodolph Perronet, who lived from 1708 to 1794. At the beginning of this period in France, the department of Bridges and Roads was under the direction of Hupeau, by whom the bridge over the Loire at Orleans was built. This bridge has nine elliptical arches of 98 to 107 English feet in length, and replaced an ancient one with nineteen smaller openings. It cost complete, over half a million dollars. The intrados curves are semi-ellipses, presenting a very satisfying outline and the piers have round ends extending above the springs and terminating in stepped semi-cones. The solid balustrade and the heavy stone work give the appearance of strength and permanence. M. Hupeau was succeeded by M. Perronet under whose direction many other fine bridges were built, including those at Trilport over the Marne, Nogent and Neuilly over the Seine, St. Maxence, and Pont de la Concorde or Louis XVI. bridge over the Seine at Paris. The **Trilport bridge** was the first oblique elliptical one and the first entirely under Perronet's direction, but the later one at Neuilly is considered his finest production. The **bridge at Neuilly,** 1768-1774, with **five elliptical arch** spans of 128 feet each and rise of 32 feet, is 766 feet long and the soffits are

conoidal, being the first appearance of this form ("cow horns") Each of the two center piers of St. Maxence bridge (1785) which is on the road from Paris into Flanders, is made of four cylinder pillars 9 feet in diameter with an open space between the middle ones, and on the deck at each end of the balustrade are shafts or obelisks. The Gignac bridge is distinctive in having a central 161-foot elliptical arch with a semi-circular one of 72 feet at each side.

81. **Pont de la Concorde,** or bridge of Louis XVI., with five segmental aches of 83 to 102-foot span, was begun in 1787 and completed in 1791. The piers are very slender, being only 10 feet thick, and the round ends extend to the balustrade in the form of columns with capitals supporting pedestals. A heavy coping with dentils and the open railing with turned balusters are interesting details.

82. During the nine years from 1804 to 1813, when M. Lamande was chief engineer of the department of Bridges and Highways, France spent more than 40,000,000 francs for bridges, many of which were erected to commemorate the victories of Napoleon. Two memorial bridges of this period over the Seine at Paris, were Pont de Jena, 1807, and Pont de Austerlitz, completed in 1813. **Pont de Jena** commemorates the battle of Jena in which Napoleon was victorious over the Prussians in 1806, and its location over the river to the Trocadero is very prominent and appropriate. It has five elliptical arches of 92-foot span and a clear roadway of 42 feet. **Pont de Austerlitz** commemorates Napoleon's victory at the battle of Austerlitz, and above each pier is a wreath surrounding the initial "N." It has five flat arch spans and the complete bridge cost over 3,000,000 francs.

83. The bridge over the Garonne river at **Bordeaux** was commenced in 1813 and continued to completion in 1822. It is chiefly notable for its large number of spans, which are

elliptical, and the combination of brick and stone, both of which give it a distinctive appearance.

84. The building of aqueducts to supply water to metropolitan districts frequently involved the construction of large masonry viaducts, such as the near Aix, which crosses the Arc river on the canal from Durance to Marseilles. This viaduct, known as the Roquefavour, is described under "Aqueducts."

85. **Pont au Change** at Paris was built in 1859, with three stone arches of 104-foot spans, carrying the Boulevarde de Sebastopol over the Seine, the bridge being the full width of the street.

86. **The Auteil viaduct,** or Pont du Jour (Fig. 31), over the Seine, has double decks, the upper story being supported on a series of thirty-one small arches with other arches crosswise

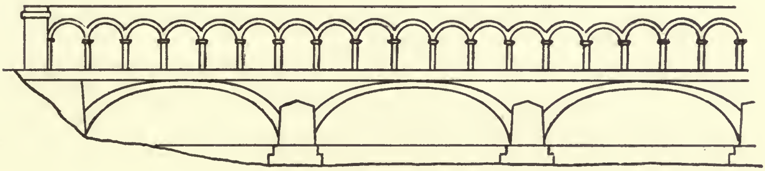


Fig. 31.

through the supporting piers. The lower deck has five arches, and over each pier is the imperial letter "N." Altogether there are not less than thirty-two bridges over the Seine within the city limits.

87. Soon after the beginning of railroad building French engineers, following the example of others in England, constructed many large railroad viaducts of stone and brick, some at a great elevation above the ground. Among these are the viaducts at Montlouis with twelve spans (1844), which was damaged during the war of 1870, but rebuilt, and Cinq-Mars, with nineteen spans (1845), both across the Loire river and valley. **The Barentin viaduct** (1844) with twenty-seven arch

spans of 50 feet, 112 feet high, fell after a great storm when nearly completed, causing a loss of $150,000. The contractor, Thomas Brassey, was advised by French lawyers that he was neither morally or legally responsible for its failure, but it is said that he considered himself morally so, and therefore, rebuilt it at his own expense. The Moret railroad viaduct over the Loing river has thirty spans of 32 feet and two larger ones of 132 feet, while the Din . railroad viaduct over the Rance has ten spans with a maximum of 52 feet and is 130 feet above the water. Other similar structures are at Chalonnes with seventeen spans, and the Crueize river viaduct at Marvejois with a height of 207. The **Morlaix viaduct**, which carries the Paris and Brest railway, is a stone structure with fourteen arch spans, an aggregate length of 934 feet, a height of 207 feet above the water and breadth at the top of 28 feet. It carries a line of railroad and a paved roadway and is built in two stories, the lower arches having a clear span of 44 feet, while the upper ones have spans of 50 feet 10 inches. The Piers are 14 feet thick at th esprings with a batter of one in twenty-two below the first deck and one in forty above it, while sideways, the batter is one in one hundred. After two years in construction, it was completed in 1863 under the direction of M. Planchet at a cost of $500,000.

88. The Chaumont viaduct (1858) is in three stories, while later ones at Altier (1860), Selle (1874), and Busetti are in double stories. Others at Aulne (1867), Vezouillac (1875), Pompadour (1875), and Rancidite (1880) are in single stories, those at Rancidite and Bussetti having every third or fourth pier heavier than the regular ones. Another stone bridge of great height is the single span 140-foot arch of **St. Sauveur**, 1860, in the Maritime Alps, springing between rock side walls with the floor 215 feet above the stream, one of the most picturesque in Europe.

89. A recent bridge of much merit, built in 1897, is located at **Verdun,** France, over the Doubs, which cost $41,000. Three spans with the center one of 134 feet, cross the stream, and the intrados curves are semi-ellipses, with circular arcs for the extrados. The whole length is 478 feet and width 20 feet. The abutments, piers and main arches are gray stone, and the spandrel arches, reddish brown brick, a pleasing color combination. The Tarn river bridge at Alby is also light and very artistic in outline. A large masonry arch on the Bellegrade-Chizery Railroad in France, from designs by Chief Engineer Picard (1909) has a span of 262 feet 9 inches, and a height of 215 feet above the valley, the deck being supported by eleven smaller spandrel arches. Centers were supported on three timber towers, and the whole work cost $90,000.

90. The earliest extensive use of monolithic concrete for modern masonry bridges is believed to be in connection with the aqueducts for the city of Paris. Concrete filling was used in the ancient Roman bridges, but on the **Grand Maitre aqueduct** a long series of spans carrying the water across the Fountainebleau valley, arches of solid concrete were employed to a great extent without stone facing.

. 91. Statistic compiled in 1873 show that 1982 important bridges existed at that time in France; 861 were built before the nineteenth century, 64 during the First Empire, 180 during the Restoration, 580 during the reign of Louis Philippe, and 297 since 1848. The aggregate length of bridges is estimated at 106 kilometers, and cost of their construction at 286,-507,761 francs.

Spanish Bridges.

92. The Madrid bridge over the Mancanares, has a series of semicircular 34-foot stone arches between heavy piers with curved ends, and the Valence bridge over the Guadalaviar, many flat segmental arches, both dating from the eighteenth

century. The Fuentecen bridge, over the Riaza, has four flat spans of 52 feet, built in the nineteenth century.

Stone Bridges in Germany, Austria, Switzerland and Belgium.

93. Germany and Austria have produced some of the most remarkable stone bridges of the last 150 years, comparing favorably with those in France and England, though perhaps not so numerous as in the latter countries. One of the earliest of the period is the long stone bridge over the **Neckar river at Heidelberg,** constructed in 1788 by the Elector Charles Theodore, whose statue now stands on the pier at one end. The chief interest in connection with this bridge is its association and history. Located close to the famous old castle and to the Heidelberg University, the place is deserving of a better structure, for the bridge shows but little merit either constructively or artistically. The roadway has a broken grade and the parapet and railings are a varied forms. On a pier near the middle of the river is a statue of Minerva while over the other piers are balcony retreats.

94. The Schloss or **Palace bridge at Berlin** was completed in 1824 from designs by Schinkel. There are two stone arches and between them a draw span, which is no longer used. It is 106 feet wide and the roadway is adorned at either side with eight groups in marble, more than life size, illustrating the life of a warrior. Other fine bridges at Berlin are the new Oberbaum and the Frederick bridges, both of which are beautiful architectural productions. The Oberbaumbrucke has double towers over the middle piers marking the position ot the channel, and over the sidewalk at one side is an overhead structure supported on a series of brick arches carrying the elevated railroad. The **Freiderichsbrucke** is a substantial masonry arch with an open balustrade and crosses the river in the vicinity of some fine monumental buildings. Over the piers at the balustrade are pedestals mounted with statues holding

aloft ornamental lamp globes, the whole forming a beautiful bridge and one in harmony with its surroundings. The Munich bridge over the Isar river adjoining the Maximilianeum is also worthy of its fine location.

95. Many of the largest stone bridges in Germany and Austria have been built since 1833 to carry lines of railroad, some of them at great height. Among these are the viaducts at Spreethal, Goeltzschthal, Elsterthal, Gorlitz, Boberthal, Konigstein, Waldi-Tobel, Jaremcze, Coppel and Wiesen. **The Goeltzschthal viaduct** on the Saxon-Bavarian railway has four tiers of brick masonry arches at the sides but only two tiers at the center. The lower central arch has a span of 94 feet and a height of 136 feet, while the upper center arch has a span of 102 feet and a height of 105 feet. It has twelve sets of arches on one side of the center and sixteen sets on the other side, making altogether eighty arch openings. It is 1900 feet long, 263 feet high and was completed in 1846 under the direction of R. Wilke. **The Elsterthal viaduct,** also on the Saxon-Bavarian railroad, is a two story stone arch viaduct with a length of 550 feet on the lower tier of arches and 918 feet on the upper tier, and a total height of 224 feet. It was built in 1851 under the direction of R. Wilke and H. Krell, civil engineers.

96. The Spreethal, Loban and Gorlitz railroad viaducts have semi-circular arches and are very imposing. The Dolhain viaduct, Belgium, with a length of 880 feet and height of 57 feet, has semi-circular spans of only 31½ feet. The bridge of Baden, near Vienna (1842), 1,430 feet long, the Neckar bridge at Lademburg (1852), 870 feet long, and the Amsterdam bridge (1874), 1,940 feet long, are all large and important. The two single span railroad bridges over the Gutach and Schwaenderholz, with spans of 210 and 187 feet, cost about $12 per cubic yard in place.

97. Another large railroad arch is the one at **Jaremcze, in Galacia,** over the Pruth river, with a span of 213 feet, and is **the** longest railroad masonry arch. The ring is 8 feet 8 inches thick at the crown and 10 feet thick at the springs. It has six approach arches at one side and one at the other, with spandrel arches at either side and was built in 1892 at a cost of $33,900. The **Waldi-Tobel** railroad bridge in Austria is somewhat similar to the Jaremcze, but is faced with rough stone, giving a decided rustic effect. It was built in 1884 under the direction of Ludwig Huss, chief engineer of the Austrian state railways, with a span of 134 feet, and the road is 160 feet above the water. The Konigstein and Boberthal railroad viaducts have thirty-four and thirty-five arches respectively, the roadway of the latter being 75 feet above water. The Wiesen viaduct in Switzerland is 300 feet above the bottom of the gorge and has a central arch span of 180 feet with six approach spans. The Albula river masonry arch at Soles in the Swiss Canton of Grisons, 500 feet long, carries a railroad at a height of 292 feet above the valley, and has a central arch of 140 feet with smaller ones at the ends, there being twelve arches altogether.

98. Two highway bridges of very unusual proportions have lately been built at Luxemburg, Germany, and Plauen, Saxony.

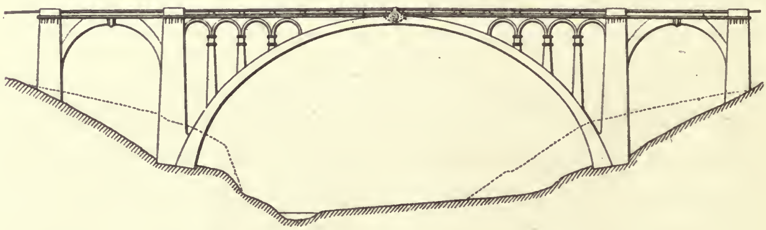


Fig. 32.

The **Luxemburg arch** (Fig. 32) over the valley of the Petrusse river, has a central span of 277 feet and its clear height is 137 feet with a rise of 102 feet and road 144 feet above the

water. The spandrel arches of the main span have an opening of 17.7 feet and the two approach spans are 71 feet long each. It consists of two parallel arches about 19 feet apart, with an outside width of 50 feet and a total length of 1,148 feet. Much saving resulted by omitting the central part, the actual cost being $270,000. The arch **bridge at Plauen,** which is the longest stone arch in the world (Fig. 33), was built in 1903 under the direction of C. H. Leibold. It crosses the valley of the Syra river, 58 feet above the ground. As the valley was used for travel and other purposes, a single arch of 295 feet and one-fifth rise was selected, with minor arches in

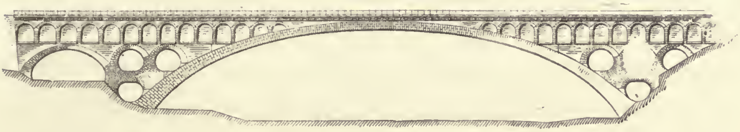


Fig. 33.

the spandrels and a very ornamental facade. The material in the arch is slate from a quarry near by, while Bavarian granite is used for moldings, balustrade, stairs, corbeled sidewalks and other trimmings. It has a total width of 56 feet and cost $125,000. The masonry viaduct over the Isonzo river near Triest and Gorz, Austria, completed in 1908, contains a river span of 279 feet, with three semicircular approach arches at one side, and six on the other. The material is limestone, and the principal arch ring which rises at each side from low skew backs, is 18.4 feet wide and 6.9 feet thick at the crown, increasing to 23.6 feet wide and 11.5 feet thick at the springs, the deck being supported on ten transverse arches.

99. A barbarous custom of the Dark Ages required that a human body be built into one of the piers, and conforming to this ancient practice, an infant was entombed in a pier of the Kerventhal bridge in Saxony in the early part of the nineteenth century. When building the Halle bridge in Germany

in 1843, a child was to have been built into it, but a chicken was used instead.

100. Other fine stone bridges are the Lombards, Roesendamms and Wandrahms bridges in Hamburg, the Albert bridge at Dresden, the Lahn near Friedelhausen, Germany, with fine stone portals and double entrance ways, the Nidda bridge near Vibel, Germany, the Zoel Elbe in Magdeburg adorned on either side with statues, the Neckar bridge near Ladenburg and the new bridge at Coepenick, Germany.

Italian Bridges.

101. The viaduct of **Civita Castellane** (1712-1864) crosses a rugged gorge 285 feet wide and 162 feet deep with a central arch of 68 feet and side openings of 33 feet each. The Arricia viaduct near Albano (1852) is 1052 feet long in three stories, with 26-foot openings in the lower story and 29 and 31-foot openings in the upper ones, and a height of 192 feet above ground. The bridge of Hannibal over the Volturno near Capua (1869) contains some remarkable features. The water is crossed with a central flat arch of 115 feet and through each masonry abutment are circular openings 30 feet in diameter instead of the usual archways. At each side of these openings are round pilasters with ornamental tops. The "Devil's Bridge" over the Sele near Poestum (1872) has a single flat conoidal arch with round pilasters extending up to the railing with battlemented tops. The bridge of Solferino over the Arno at Pisa (1872) has three flat elliptical spans, the side ones, 85 feet and the center, 92 feet. A bridge over the Fegana near Lucca (1877) has a central flat segmental arch of 156 feet between heavily paneled abutments, giving the appearance of great strength. The two story viaduct of Pozillo (1880) is 89 feet high with 33-foot semicircular arch openings and a total length of 530 feet. Other long bridges over the Po at Turin of 1881 with several spans are Ponte di

Valentino, 550 feet long, and Ponte di Vanchiglia, 410 feet long, the latter with conoidal intrados. This form seems to be a favorite with modern Italian engineers, for the bridges at Capua and Poestum have similar outlines.

102. Several modern Italian bridges cross the Tiber river at Rome, including the **Margherita bridge** with three arches of 99 feet each, built in 1891 under the direction of Vescovali and carrying the Porta del Popolo over the river above the new Palace of Justice. The Victor Emmanuel bridge crosses the Tiber near the bend of the river adjacent to the Castle of St. Angelo and was erected in the years 1905 and 1906.

103. A long span stone arch bridge, built in 1903, carries the railroad between Colico and Soudrio, over the **Adda river.** It is a three centered arch with a clear span of 230 feet, an outside width at copings of 16 feet and a width at abutments of 20.5 feet. There are steel hinges at the springs and crown and the crown thickness is 4.7 feet. The main arch and all faces are granite, but the spandrel arches are concrete. It is the largest masonry railroad arch erected up to the present time. The water below the bridge has a maximum rise of 21 feet.

104. On the Damascus and Mecca line, was completed about 1892, a stone arch viaduct with ten semicircular arches of 20-foot span each, and two decks. The upper deck carries a railroad 80 feet above the valley, while the lower one is a highway passing through openings in the piers.

British Bridges.

105. This period in England is notable for the large number of fine stone bridges, many of which have not since been excelled. They were chiefly the work of a few engineers, who, profiting by the completion of the new Westminster bridge and those recently built in France, developed the art of stone bridge building to its highest state. The leading

engineers of the period were Robert Milne, John Smeaton (1724-1792), John Rennie (1761-1821), and his two sons, George Rennie (1791-1866) and Sir John Rennie (1794-1874), Thomas Telford (1757-1834), George Stephenson (1791-1848), and his son, Robert Stephenson (1803-1859), Sir Marc Isambard Brunel (1769-1849), and his son, Isambard Kingdon Brunel (1806-1859), and Thomas Harrison. Mr. Rennie's first bridge was a three-span arch in Midlothian over the Water of Leith, built in 1784, but his best and largest ones were the Southwick, Waterloo and London bridges. The London bridge was completed by his sons, the younger one being knighted in 1831 when the work was finished. Sir John Rennie was also engineer on the Kelso, Leeds, Musselburg, Newton-Stewart, Boston and New Galloway bridges.

106. The forward movement in bridge building in Great Britain was due chiefly to the establishment by the Government of a board or commission with power to construct roads and bridges throughout the islands, conditional on the local municipalities or towns desiring such roads, bearing a part of the expense. The chief engineer for this commission was Thomas Telford, a man of strong character and leadership, who had once been a practical stone mason. Under this Board more than 1,000 miles of roads were built in England and Scotland, including over twelve hundred bridges. Telford's first stone bridge was a three-span elliptical arch across the Severn at Montfort, built in 1792. In addition to stone bridges, he built many other kinds, including the Menai and Conway suspensions, as well as canals, harbors and other public works. Another prominent engineer of the period was George Stephenson, chief engineer of the Stockton and Darlington railway. He and his son, Robert Stephenson, built many stone bridges and railroad viaducts, and some notable cast iron and wrought iron bridges, including the Britiannia in Wales and

the Victoria tubular bridge at Montreal. Sir Marc I. Brunel, the French engineer who was knighted in 1841 for building the Thames river tunnel, being forced to leave France, came to America and undertook the engineering of many public works here and in England. He prepared competitive plans, which were not accepted, for the national capital building at Washington, and was later appointed chief engineer of the city of New York. In 1833 his son, I. K. Brunel, was made chief engineer of the Great Western railway of England, and he designed and built many notable bridges and viaducts.

107. Soon after the completion of the Westminster bridge at London, a movement was started for building a third one over the Thames, now known as the **Blackfriars bridge.** It was designed by Robert Milne and built in the years 1760 to 1768, with nine multi-centered arches and a total length of 995 feet. It was 43 feet wide and the piers, which had double ornamented columns above the springs, were built in caissons, the whole bridge costing, when finished, 152,800 pounds. It was repaired in 1833 at a cost of 105,100 pounds and replaced in 1865, with a cast iron bridge of only five spans. Both the Westminster and the Blackfriars failed by scouring the foundations.

108. The **Kelso bridge** at Glasgow over the river Tweed near its junction with the Teviot, was designed by Mr. Rennie and built 1799-1803. It has five elliptical arches of 72-foot span, 21-foot rise, and is 26 feet in width. The piers are 12 feet thick and have rounded ends surmounted by semi-columns extending up to the cornice, which is supported between the piers by numerous brackets. The roadway is level, 29 feet above the water, and its total length is 410 feet. The parapets are solid with ornamental lamp posts over the piers. This was Mr. Rennie's first important work.

109. The **Waterloo bridge** at London, designed by John

Rennie, Sr., and George Dodd, was built in the six years prior to 1817, and had nine elliptical arches of 120-foot span and 34-foot rise, supported on piers with semi-circular ends. The design was planned to conform with the architecture of Somerset House, which is in the near vicinity. Piers 30 feet thick at the base and 20 feet at the springs, are ornamented above the springs with twin Doric columns similar to those on the Kelso bridge. The level roadway is 28 feet wide with two seven-foot walks and has lamp posts over the span-centers—an unusual arrangement. It is faced with granite and cost $4,687,000.

110. **London Bridge** (Fig. 34) is perhaps better known than any other. The present structure of 1821 to 1830, replaced the old bridge that was lined with shops and houses.

Fig. 34.

(Fig. 25.) The new one is a very fine illustration of high-class stone construction. There are five elliptical arches, the center one being 152 feet long, the two adjoining, 140 feet, and the end ones 130 feet. Its entire length is 926 feet. The

original width was 54 feet, and it is estimated that 120,000 foot passengers and 25,000 vehicles cross the bridge daily. It was designed by the elder John Rennie and constructed under the direction of his two sons, George and Sir John Rennie, Jr. The total cost with approaches was 1,458,000 pounds, while the bridge alone cost 426,000 pounds. In the years 1902 to 1905, Sir Benjamin Baker increased the width 11 feet at an additional cost of $500,000 by adding brackets and changing the solid parapet to an open one. The two center piers are 24 feet thick and are founded on cofferdams, and the roadway is 60 feet above the water. Stone voussoirs vary in thickness from 4 feet 9 inches at the crown to 9 feet at the springs and the face work throughout is granite. The engineers on the reconstruction were E. Cruttwell and Sir Benjamin Baker. An excellent example of more recent construction in masonry is the Putney public bridge designed by Sir J. Bazalgette and built at a cost of 240,000 pounds.

111. **Essex and Queen's bridges** over the Liffy river at Dublin were built in 1753 and 1768 respectively. The original Essex bridge was the work of Sir Humphrey Jarvis (1676) but it was rebuilt in 1753 from plans by George Semple. The Airon bridge at Dublin (1684) was destroyed 1763, and rebuilt as Queen's bridge by Colonel Vallency (1768). Many others were also erected throughout the island, including those at Killarney and one over the Lea at Cork. But the finest one in Ireland is the **Wellesley bridge at Limerick,** designed in 1827 by Alexander Nimmo. The five arches are segmental on the face with conoidal (cow horn) soffits. It is 41 feet wide, 410 feet long and has a tower at one end.

112. **The Tongueland bridge** with a single large span of 118 feet, has three pointed 9-foot arches in each abutment. It has three lines of inside spandrel walls and a battlemented railing, giving it a distinctive appearance. The **Cartlane Crags**

bridge over the Mousewater (1821), 122 feet long in three spans, is imposing and very artistic. The Pathhead bridge over the Tyne (1830) and the Dean bridge at Edinburg (1831) have much smaller rise for the arches under the sidewalks than those under the roadway, with corresponding offsets in the piers.

113. The largest stone arch bridge in England is the **Grosvenor** at Chester over the Dee (Fig. 35.) It was designed by Thomas Harrison and built in 1833 by James Trubshaw—contractor—at a cost $250,000. It has a single arch of 200 feet, 42-foot rise and 140-foot radius, supporting a roadway

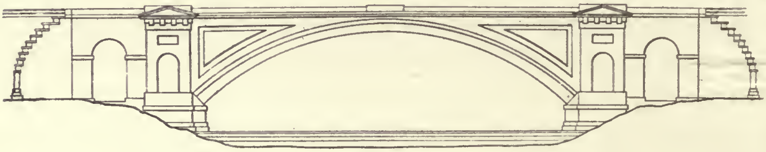


Fig. 35.

33 feet in width. The ring stones vary from 4.5 feet in thickness at the crown to 7 feet at the springs, and its total length is 345 feet. The springs are unfortunately too low to escape high water, a difficulty which might have been avoided by using an elliptical intrados similar to that on the Trinity bridge at Florence.

114. The old **Forth bridge at Stirling** in Scotland, designed in 1832 by Mr. Stephenson, has five segmental arches, the center one being 60 feet. Another notable one in Scotland is the new bridge at Ayr, the third one on the same site. It is one of **"The Twa Brigs o' Ayr"** made famous by the poet, Robert Burns. The old one, which was 12 feet wide between parapets, with four spans of 52 to 53 feet, has recently undergone extensive repairs for the purpose of preserving it. Of plain design, used for pedestrians only, it stands out in striking contrast to the new one with its ornamental balustrades and

other features. Other fine stone bridges of this period are those on the private estates of England and Scotland, among which are the Chatsworth and Wilton bridges. The original **Broomielaw bridge** at Glasgow, Scotland, was planned by Thomas Telford and built during 1833-1836. It crosses the river Clyde and connects the northern with the southern divisions of the city. The old bridge has seven segmental arches varying in length from 52 to 58 feet with piers 8 to 9 feet in thickness at the springs. The walks were paved with stone slabs and the road with brick. There are two lines of railway and a smooth stone track for heavy trucks. It was 58 feet wide in the clear between parapets, with arch and spandrel face of granite, and piers of free stone. The pier ends were octagon up to the springs, and continued to the cornice in the form of ornamental octagon pedestals in the balustrade for the lamp standards. With increased travel, the bridge was too narrow for the demand upon it, and in 1895-99 was taken down and rebuilt, the width being increased to 80 feet. The present bridge contains 80,000 cubic feet of granite, and each of the six piers rest on four cylinders 15 feet in diameter, filled with concrete. The piers are new and are more massive than the old ones, and the whole bridge is faced with granite, the parapets being polished. The engineers on the construction were Blyth and Westland.

115. **Railroad building** began in England about 1830 and in the following twenty years many large **brick railroad viaducts,** mostly with semicircular arches, were built chiefly under the direction of Brunel, Stephenson and Harrison. Such viaducts are those at Maidenhead (1837) the earliest one, and at Dalton, Victoria at Washington, Congleton, Ouse Valley, Warfield, Lockwood, Berwick, Dee, Stockport, Llangallen and Anker. Though of very plain construction without ornament, these viaducts have often, because of the great size, a more

imposing appearance than lower highway bridges, some being over 150 feet in height with thirty to forty spans. The arch bridge at **Ballochmyle** over the Ayr, has a center semicircular arch of 180 feet with three smaller 50-foot arches at each end, the center span being the longest railroad arch in England. There was, however, little or no uniformity in reference to the proportion of span length to height, for the Ouse Valley viaduct, 94 feet high (1841) and the Lockwood, 122 feet high (1849), were made with 30-foot spans, while the Warfield, 90 feet high (1846), the Berwick, 124 feet high (1850), the Dalton, 73 feet high and the Llangallen viaducts all have 60-foot spans, and the Congleton 101 feet high (1839) has 61-foot spans. The viaduct over the river Dee has nineteen spans of 90 feet, and the Rugby (1839) on the Midland railway, over the Avon, eleven arches of 50 feet each. A more recent one (1880) called the Harrington viaduct, carries the Midland railway on eighty-two arches of 40-foot span.

116. The **bridge at Carlisle** over the river Eden with five semi-elliptical arches, designed by Sir Robert Smirke, is deserving of special mention, because of its pleasing outline and fine detail. The proportion of rise to span with full centered intrados have been carefully chosen to produce the best effect.

American Bridges.

117. One of the earliest stone bridges in America is the **Witmer bridge** near Lancaster, Pa., built by A. Witmer and Mary Witmer, his wife, and completed in the year 1800. There were, however, few important stone bridges* in America prior to 1820, when the construction of the **Rochester** stone **aqueduct** was commenced under the direction of David Stanhope Bates. Another stone aqueduct at Washington over the Potomac river was commenced in 1837, with seven arch spans, and the

*The stone bridge at Ipswich, Mass., with two spans of 28 feet, built by Col. John Choate (1764) is probably the first of its kind in the United States.

same year witnessed the beginning of the Croton aqueduct over the Harlem river at New York City, carrying the Manhattan water supply into the city on a series of stone arches known as **High Bridge** (Fig. 36). The water supply for Washington is brought into the city over a single masonry arch, the Cabin John bridge (Fig. 37) which for many years held the record as the longest masonry arch, but has since been exceeded by the Luxemburg, Plauen and Salcano, as

Fig. 36.

well as by several concrete bridges now under construction. **Cabin John bridge** carries a road and the aqueduct over Rock creek, and was built under the direction of General M. C. Meigs during the years 1857-64. A third notable stone aqueduct, generally known as **Echo Bridge**, is that at Newton Lower Falls, Mass. (Fig. 38), built by the Boston Water Commission under the direction of Chief Engineer Fitzgerald, to carry a conduit across the Charles river. It is often viewed by Boston residents, especially in the summer season. The smaller spans are all at one end, making the bridge unsymmetrical, but the shrubs and foliage are so arranged that the

Fig. 38.

large span only is conspicuous from the roadway. These bridges are more fully described under "Aqueducts."

118. The introduction of **railroad building** in America about 1830, made a demand in some places for more permanent bridges than those of timber, though the necessity for rapid construction usually prevented the building of permanent

Fig. 37.

structures until after the road was in operation. The opening and settlement of new countries ever since the founding of the Roman empire, has always been dependent on the construction of roads and highways, and in America with so large a territory to develop, the completion of roads and their operation could not be delayed for permanent structures. The custom, therefore, has been to erect temporary ones at first, and renew or replace them with better ones after the road is opened to travel. In 1835 the Carrollton stone railroad viaduct was built over Patapsco Creek under the direction of

Benjamin Latrobe, and in 1847 was commenced the largest one of the kind—Starucca viaduct—carrying the Erie railroad over Starucca Creek. It has seventeen flat arch spans 51 feet long each, a height of 110 feet and a total length of 1200 feet. It was built for only a single track, but a second one has since been added without alterations. The material is sandstone, piers 7 feet thick at the springs, and deck 25 feet wide. It was built under the direction of Engineer Adams and is similar to many in England of the same time. Few other important stone railroad bridges appeared in America until 1881, when a stone arch viaduct was begun at Philadelphia to carry the Philadelphia and Reading railroad over **Wissahickon Creek** near its mouth at Manayunk. It is prominently situated and can be seen for quite a distance up and down the Schuylkill river and from both banks. It was built from designs by C. W. Buckholz, chief engineer for the railroad company, and has five spans of 70 feet each, with a rise of 23 feet. The thickness of the arch ring is 3 feet, the outside width of bridge 28 feet and the thickness of piers at springs 9½ feet. Including the four small arches, 10 feet wide, two in each abutment, the extreme length of bridge is 510 feet. The height above the drive beneath 80 feet, and above the foundations, 103 feet. It contains 15,400 cubic yards of Talcose slate masonry and cost complete $375,000. Two tracks are carried by it across Wissahickon creek and valley, which is part of the Fairmount Park system. A stone railroad viaduct quite similar to that at Wissahickon was at **Painsville, Ohio,** over the Grand river. It had four semicircular arches of 80-foot span and a height of 90 feet above the water, and was owned by the Lake Shore and Michigan Southern railroad, E. A. Handy, chief engineer. Piers were 10 feet thick at the springs and arch rings 3 feet thick, but it was replaced with a single concrete arch in 1909.

119. Another notable railroad bridge constructed during the years 1881 to 1893, is one over the Mississippi river at **Minneapolis, Minn.,** carrying two tracks of the union railroads into that city. Col. Charles C. Smith directed the work. There are four spans of 100 feet, one each of 71 feet, 43 feet and 40 feet, and fifteen of 80 feet. The piers are made of St. Cloud gray granite, the regular ones being 7 feet thick, while the abutment piers have twice that dimension. Above the piers, the material is Kasota limestone. A portion of the structure, 800 feet in length, is on a 6 degree curve, and as it is situated just below St. Anthony Falls, the view from the bridge shows this most interesting part of the river and is quite picturesque. It contains 30,550 cubic yards of masonry, 18,000 cubic yards of stone filling and has a total height of 82 feet, 65 feet being above high water. It is 36 feet across the top, and the masonry part alone cost $650,000.

120. The greatest forward movement in the building of **stone railroad bridges** in America began in 1888, when the Pennsylvania Railroad company under the direction of William Brown, chief engineer, commenced replacing its wood and iron bridges with permanent ones of stone and concrete. Several of these safely resisted the Johnstown flood of 1889, though one over the Little Conemaugh river was destroyed. The test was, however, so successful that for twenty years, that railroad has continued rebuilding bridges in masonry, and many of great magnitude have been erected, including those over the Susquehanna river at Rockville, Trenton, Brunswick, Coatsville and Shocks Mills, as well as many other smaller ones. The bridge at Trenton has eighteen spans, while those at Brunswick, Coatsville and Shocks Mills have twenty-one, ten, and twenty-eight spans, respectively. The **Rockville bridge** with forty-eight spans of 70 feet, and 20-foot rise, is 3,820 feet long, contains 100,600 cubic yards of masonry and

cost $800,000. It is 52 feet wide, supported on piers 8 feet thick at the springs and had a concrete body with stone facing. Previous to building the stone bridge in 1901, three different iron and steel bridges had occupied the site, each one being succeeded by a stronger one.

121. Following the example of the Pennsylvania Railroad company, other roads began replacing their old bridges with permanent masonry ones, and in the last ten years many of this kind have been constructed on the railroads of the United States, including the Lake Shore and Michigan Southern, the Big Four and other branches of the New York Central system, the Fitchburg, and several other roads. The two span bridge at **Bellows Falls,** carrying the Fitchburg railroad over the Connecticut river, replaced an old wood Burr truss, with track 80 feet above the water. The spans are 140 feet each with 20-foot rise and has a 27-foot width for double track railroad. The location with rock side walls and a rock support in the middle of the river was inviting and economical for a masonry arch. It was built in 1899, under the direction of A. S. Cheever, chief engineer.

122. The building of ornamental **park bridges** in American cities began in 1850, when George Kellar, architect, of Hartford, Conn., designed the memorial bridge at **Bushnell Park** (Fig. 39). It is one of the most beautiful park bridges in America, and was built of Portland brown stone, with five arch spans, at a cost of $15,000, being widened in 1885 at additional cost of $11,300. The three center spans are semicircular while the two end ones are three-centered, all having a clear span of 25 feet. The width was originally 35 feet, but was increased to 41 feet by removing the spandrel masonry down to the arch rings and rebuilding the deck, the extra width being carried on stone brackets. Located close to the State Capitol the beautiful memorial arch forms a more prominent feature

than the bridge itself. The roadway passes beneath the arch, while sidewalks are curved outside the memorial piers. In summer the whole is surrounded with ivy and other climbing vines, and forms one of the most beautiful features of the landscape. The memorial arch cost $60,000 in addition to the cost of the bridge itself.

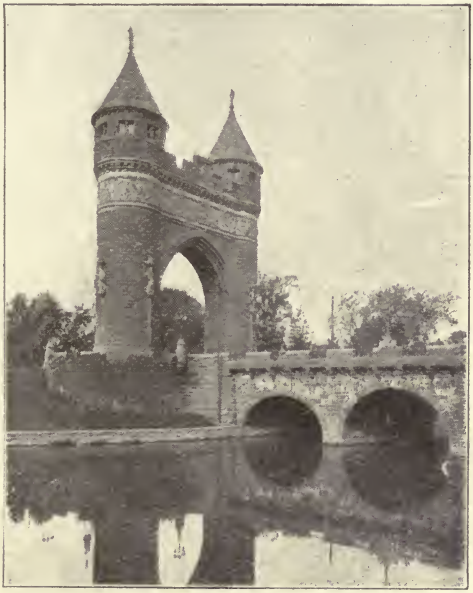


Fig. 39.

123. In 1891, the city of Boston began on quite an extensive scale, the building of **ornamental stone bridges** on the Fenway and other portions of its park system. Fifteen or more bridges were completed, including those at the Bridle Path, Audubon Road, Leverett Pond, Forest Hills, Scarboro Pond, Boylston Street, Charlesgate, Agassiz, Stony Brook, Railroad Brook, Fen Bridge, Tremont Street, Brookline, Bellevue and Neptune bridges. **Stony Brook bridge** (Fig. 40) contains five arches of 10 feet each, three of which are over the

Fig. 40.

water and two over the foot paths. It is 80 feet wide between parapets, and the arches are supported on piers with transverse arches underneath the deck. At each end is a flight of steps from the sidewalk on the bridge to the walks beneath it. The face work masonry is spreckled brick with trimmings of Milford granite, and at each stairway is a drinking fountain. The barrel vaults beneath the floor are lined with glazed brick of different colors laid in patterns. It was designed by F. L.

Fig. 41.

Olmstead & Co. and Walker & Kimball, architects, and cost $40,000. Another bridge in the Boston park system is that which carries the parkway over the traffic road leading from **Forest Hills street** to the entrance of Forest Hills cemetery. (Fig. 41.) This bridge is 125 feet in length and the main span has a segmental arch of 45 feet. A stairway connects the sidewalk over the bridge, with the foot path along the traffic road beneath. The slopes of the bank are supported by retaining walls on the lines of the traffic road. Crossing the bridge at the end the masonry piers for a gateway have been built, the

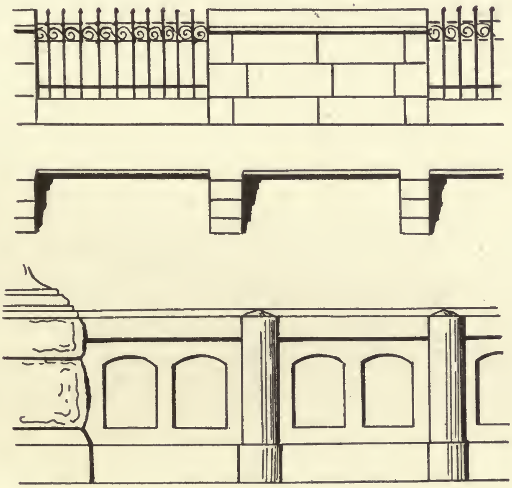
piers of the side gates being connected with the parapets. This gateway has three openings, one each for the drive, the road and the walk. At one side of the gateway is a recess with seats, and a drinking fountain. The total cost was $51,000. All face work is of seam faced granite, except the coping and cap stones which are of red granite. The soffit is light colored brick, while the remainder of the arch is of common brick.

124. Following the lead of Hartford and Boston, the cities of Milwaukee, Detroit, Pittsburg, New York, Philadelphia and Chicago, built many **ornamental stone bridges** in their parks, many of which were described by the author in the American Architect of 1901. Detroit has a greater number of ornamental park bridges than any other American city, twenty or more being located in Belleview, Clark and Belle Isle Parks. They are of various outlines and built of different materials, most of them being constructed in 1893. A stone arch over **Cresheim creek** in Wissahickon valley, at Philadelphia, Pennsylvania, was built in 1892 to carry a sewer over Devil's Pool, and in the following year some ornamental stone and brick bridges were erected in Lake Park, Milwaukee, from designs by Oscar Sanne. A brick arch in this park was built in the same year with the body of the arch made of five rings of hard burned sewer brick, spandrel faces and wings of brown brick and the arch blocks on the face, and also trimmings and railings, of terra cotta. It has a length of 100 feet and cost $10,500.

125. The competitive designs submitted in 1885 for the proposed **Washington bridge** at New York City, contained three designs of much merit, for stone arch bridges. One by W. J. McAlpine has six elliptical arches with a maximum of 210 feet, while another submitted by the Union Bridge Co. proposed three segmental arches of 280-foot clear span. A design by J. W. Adams shows three principal arches of 196

feet with many smaller ones at each end. The bridge in **Garfield Park,** Chicago, with others in the same city, were part of the preparation for the World's Fair of 1893.

126. A park bridge of much larger proportion than those previously described, was built in **Schenley Park,** Pittsburg, in 1896, over a ravine 70 feet deep, known as Pierre Hollow. It has a clear span of 150 feet and a total length of 341 feet, with an extreme width of 85½ feet. It is a segmental arch with 36-foot rise, carrying a roadway and two footwalks, and was built under the direction of the Department of Public



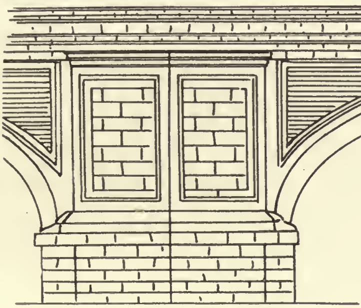
Works, with H. B. Rust as engineer. It has heavy paneled pilasters at each side of the arch, the spandrels are relieved with panels, and contains 12,360 cubic yards of masonry. The cost was $112,000, and it is one of the finest heavy stone arches in America. In the same year (1896) was built the **Rittenhouse Lane bridge,** Philadelphia, carrying the Wissahickon drive over Wissahickon Creek, replacing the old

wooden Red Bridge. The material is rock faced ashlar from a near-by quarry, and it has a clear span of 105 feet, a rise of 11 feet, and a 25-foot road and two walks, paved with asphalt. It is on a slight skew and the depth of key is 3 feet, the arch springing from lines above normal water. The right abutment is unusual but attractive. It was designed under the direction of Russell Thayer, chief engineer of Fairmount Park Commission and cost, including removal of the old bridge, $27,700.

127. The competitive designs received by the United States Government in 1900 for the proposed bridge across the **Potomac river** at **Washington,** called forth some of the finest bridge designs which have ever been made in America, varying in estimated cost from 2½ to 15 millions of dollars. The Government asked for plans showing one and two decks, widths of 60 and 80 feet, with a length of about 4,000 feet. A design by George Morrison showed five limestone and granite arches of 172 to 183 feet, with bascule draw spans at each end. William R. Hutton submitted plans with two central steel arches of 550 feet with a draw span between them, and six elliptical masonry arches of 100-foot span at each end, while others of great merit were submitted by William Burr and L. L. Buck.

128. The four span arch bridge (1903) at **Watertown, Wis.,** over Rock river, is plain and substantial with arch ring and cornice of different stone from that used in the spandrels. The spans are 64 feet with 16-foot rise, width 30 feet, and length of 360 feet. It replaced an iron bridge, and cost $40,700. For several years there had been a movement by interested parties to build a bridge across the **Connecticut river at Hartford,** to replace the old covered wooden bridge which had been in use since 1818. The matter was suddenly forced on public attention by the burning of the old wooden bridge in May,

1895, and a commission was then appointed, with Senator Bulkley as chairman, to proceed with the building of a permanent one, which resulted in the present stone arch bridge being opened to travel in 1908. It has nine spans varying in length from 68 to 119 feet. The regular piers vary from 13 to 19 feet in thickness, and the two abutment piers are 40 feet thick. It is 82 feet wide and 1,100 feet long and was built of Maine granite at a cost of $1,600,000. A. P. Boller was consulting engineer and E. M. Wheelwright, architect.



TRINITY BRIDGE

CHAPTER VI.

PONTOON BRIDGES.

Assyrian and Persian Bridges.

129. The earliest pontoon bridges were probably those used by ancient armies, since they were mentioned by Homer as common in his time about 800 B. C. The writings of Lucarus, Herodotus and Xenophon state that pontoon bridges with casks as floats were used for military purposes. The earliest bridge of this kind of which records are extant is one made by **Cyrus, King of the Persians,** for transporting his army in the year 536 B. C., stuffed skins being used as floats. Babylon was taken, 538 B. C., by the Persian army under Cyrus, diverting the course of the Euphrates and entering the city at night under the water gates of the river. They knew, therefor, both how to bridge the river and to dam it.

130. Darius Hystaspes, fourth King of the Persians, who began to reign 521 B. C., built a bridge of boats across the **Danube river** (510 B. C.) when engaged in his Scythian warfare. In 493 B. C., the same King, on a Scythian expedition when about to invade Thrace, constructed a bridge of boats over the **Bosphorus** at a place where it was 3,000 feet in width, over which he marched his army of 600,000 soldiers. His head bridge builder was Mandrocles of Samos.

131. In 480 B. C., Xerxes, King of the Persians, who succeeded his father, Darius, built a double bridge of boats at Abydos, or between Sestos and Madytus, over the **Hellespont** (or Dardenelles), which separates Europe from Asia. The strait varies from one to four miles in width and the bridge is

believed to have been at least 5,000 feet long. Herodotus says that the first bridge was destroyed by a violent storm, and in great anger, Xerxes ordered the engineers or builders to be executed and the water of the Hellespont to be scourged with rods and blasphemous words. Xerxes then built two other pontoon bridges, one of which on the side adjoining the Euxine Sea, was supported on three hundred and sixty, and the other on three hundred and forty anchored boats of the largest size used by the ancient navies. The first were placed transversely, and the others parallel with the current to diminish the strain on the cables. The boats were connected with six large cables of white flax, extending the whole length of the bridge and fastened to piles on either shore, the cables being drawn tight with wooden capstans. The platform, which was protected by a railing at each side, consisted of trunks of trees laid across the cables and covered with flooring and a layer of earth. The work was done by Egyptian and Phoenician artisans. Over these bridges Xerxes marched his army of 2,000,000 men across into Europe when on his way from Sardis to conquer Greece and seven days and nights were occupied in making the passage.

Roman, Grecian and Chinese Bridges.

132. At a later period the young Emperor—Alexander the Great—who died when only thirty-three years of age, built a pontoon bridge over the river **Ganges,** about 330 B. C., for the purpose of transporting his soldiers, and in crossing the **Oxus,** 327 B. C., he used rafts made of hides stuffed with straw, as all the available boats had been burned. He was accustomed to carry with his army a kind of boat in sections, which could be joined together when required for use. Pyrrhus, King of Epirus (318-272 B. C.), also had a bridge of boats on the Adriatic Gulf. **Caligula's bridge,** referred to under Roman Arches, is thought by some historians to have been con-

structed chiefly on boats. It was three miles long and was in the form of a crescent across the bays of the Puteoli and Baiae, or Tyrrhene Sea, and was supported over the water on a double row of boats or pontoons. The roadway was made of plank covered with earth and gravel, and the deck was lined on either side with shops and houses, and was illuminated at night with torches. Caligula's boast was that he would turn sea into land, and night into day, and when it was completed, the Emperor had great festivities, lasting for several days, which terminated by his ordering a large number of the citizens to be thrown into the sea. The date of completion was in the latter part of his reign, about 40 A. D.

133. Movable boat bridges were common in China, and one in the province of Chausi, at the junction of two rivers, was made with one hundred and thirty barges, chained together and arranged to open for the passage of vessels. In the fourth century A. D., the Greeks, under Emperor Julian, used boat bridges for crossing the Tigris and Euphrates rivers in their retreat from Persia.

The Pontoons.

134. Floating military bridges which had been used since the days of Cyrus, had boats or pontoons five to fifteen feet apart in the clear, supporting a platform ten to twelve feet wide, made of plank on stringers, but pontoons for many old Roman bridges were of wicker work covered with hides. In succeeding centuries the armies of other countries have made their pontoons with wooden frames covered with plank, sheet copper, sheet iron, india rubber, or canvas water-proofed with tar or paint. The Germans, in the seventeenth century, used timber pontoons covered with leather, and the Dutch, similar ones covered with tin, while the army of Napoleon preferred copper. For ease in transporting, they are sometimes made in two or more pieces, which were fastened together be-

fore being launched. Recent ones have water-tight compartments, so a single leak will not cause them to sink, and the platforms usually lie on trestles standing in the bottom of the floats. Floating piers have also been made of an assemblage of casks or logs lashed together, with sufficient buoyancy to sustain their loads, closed casks being floated on their side and open ones on end.

135. Floating bridges have frequently been assembled either up or down stream from their final position, in a place sheltered from the enemy or from a rapid current, and afterwards towed or swung around into position in either one piece or several sections. This plan was adopted by Napoleon for a bridge over the Danube the day before the battle of Wagran. The quiet water around an elbow of the river on the inner side has been found convenient for this purpose.

Mediaeval and Modern Pontoon Bridges.

136. The Servians used a pontoon bridge in the fourteenth century for crossing the Danube to assist in the defense of Nicopolis, and a bridge of boats over the Rhine between **Cologne and Deutz,** Germany, was constructed in 1674 and was replaced by a new one in 1832. (Fig. 43.) It is 1,400 feet long and carries a highway and pedestrian travel and has a wooden floor which is renewed occasionally as required. The Rouen bridge of boats was 900 feet long, and paved with stone, and was very firm under heavy travel, the boats being anchored with chains.

137. **A floating bridge,** 511 feet long, which was probably the only one of its kind, was built in 1802 near **Lynn, Mass.,** over a pond which was believed to have no solid bottom. It was made in three sections, by Moses Brown, and was floated into position. The platform was of timber, 5½ feet thick, but it had so often been re-floored that its thickness in 1904 was 17 feet. It was then so watersoaked that light loads

passing over it caused it to sink below the surface of the water, and it was replaced by a modern bridge, though the old one still remains. The only similar one known was made by George Stewart of Port Hope, Ontario, who many years ago built a **floating bridge** like a corduroy road, three quarters of a mile long between **Sturgeon and Scugog** lakes. Rafts 30 feet square of flattened timber were connected by six or seven longitudinal beams on which a platform was laid. A floating

Fig. 43.

bridge at Hertford, North Carolina, was supported on empty barrels, and was used for fifty years. A bridge over Chemong Lake near Peterborough, Ontario, with a length of 3638 feet, was built about 1900. The fixed approach is 913 feet long, and the pontoon 2620 feet, which contains a draw of 105 feet. At five places, the road is 24 feet wide to permit teams to pass, but the rest of the deck is only 18 feet wide. It cost $26,000.

138. Pontoon bridges were largely used by the American armies during the Civil war of 1862-65. One over the Potomac at **Harper's Ferry,** Va., containing sixty boats, was built February, 1862, in a period of only eight hours. The river was in freshet condition, 15 feet above summer level, and was filled with ice and drift, but the bridge, when finished, safely carried the heavy army wagons, cavalry and artillery. The Rapidan, Rappahannock and other rivers were similarly crossed.

139. The bridge of boats over the **Danube at Budapest** which existed previous to 1837, was removed in the winter seasons because of danger from ice, and travel was taken over the river, either in ferries or on the ice, which in 1838 was 6 to 8 feet thick. For several months of each year travel had been accompanied with much uncertainty and risk, and as these conditions were not satisfactory, the new suspension bridge was erected in 1847. The pontoon bridge over the **Rhine at Maxau,** Germany, had a portion 768 feet long supported on thirty-four pontoons, though the total length with approaches is about 1,200 feet. It is 40 feet wide with a single line of rail track in the middle and a highway on each side, but only light train loads and an 18 ton locomotive are permitted on the bridge. The wood pontoons are each 12 feet wide, 4½ feet deep and 65 feet long. It was opened in 1865 after twelve months in construction. Another large pontoon bridge, erected in 1873, crosses the **Hoogly river** at **Calcutta,** India. It is 1530 feet long and the deck is supported on twenty-eight rectangular iron floats coupled together in pairs, and held in position with 1¾-inch chain cables, fastened to anchors weighing three tons each. The anchors are placed on the upstream and downstream sides and each pontoon is divided into eleven separate compartments, with the top three or four feet above water. The pontoons are 10 feet wide, 8 to 11 feet

deep and 160 feet long, to prevent their oscillating or tipping sideways. The deck is 63 feet wide and 27 feet above the surface of the river, which has a current of six miles per hour. An opening for the passage of boats can be made when desired by removing four pontoons, which operation occupies a period of 15 minutes.

140. A large pontoon railroad bridge in America over the Mississippi river between **Prairie du Chien,** Wis., and North MacGregor, Iowa (1874), crosses the river and an island which divides the channel into two parts, the West channel being 1,500 feet wide, while the East one is 2,000 feet, each channel being provided with a draw span 408 feet long. The total length of bridge including the part over the island is 7,000 feet. The pontoon bridge at MacGregor was rebuilt in 1898 by Captain M. J. Godfrey, who designed and built many of the best river steamers on the Mississippi river and its tributaries, and in other countries. A few years previously, he also built the Read's Landing pontoon bridge, owned by the Chicago, Milwaukee and St. Paul Railroad, Mr. Onward Bates being then chief engineer of the road. Another over the Mississippi river at Nebraska City (1888) is 2,124 feet long, and has a 528-foot draw span operated by the current, under the control of one man. Other interesting ones cross the Indus at Khushalgarh, and the Diena at Riga. A temporary pontoon bridge was recently used at Chicago during the construction of a permanent bascule, and the revolving draw span at Weed Street (Fig. 42), Chicago, is supported at the outer end on a float, while the rear end is hinged to the deck. The Weaver river swing bridge at Northwich, England, is also supported on a floating center pier. Many others might be mentioned, such as those at St. Petersburg, Presburg, Coblenz, Seville, Ehrenbreitstein, Carazoa, Colombo in Ceylon, and Portsmouth in England.

Name.	Date.	Builder.
Euphrates river.	536 B. C.	Cyrus.
Danube river.	510 B. C.	Darius.
Bosphorus.	495 B. C.	Darius.
Hellespont.	480 B. C.	Xerxes.
Ganges.	330 B. C.	Alexander.
Oxus.	327 B. C.	Alexander.
Bay.	40 A. D.	Caligula.
Tigris.	4th Century.	Julian.
Danube.	14th Century.	Servians.
Rhine.	1674.	....
Rouen, France.	18th Century.	....
Lynn, Mass.	1802.	Moses Brown.
Port Hope, Ontario.	19th Century.	George Stewart.
Potomac, Harpers Ferry.	1862.	U. S. Army.
Rhine.	1865.	....
Hoogly.	1873.	....
Mississippi, Prairie du Chien.	1874.	....
Missouri, Nebraska City.	1888.	....

Fig. 42.

CHAPTER VII.

AQUEDUCT BRIDGES.

141. The most important of the old Roman bridges were those in connection with their aqueducts. Remains of about one hundred still exist in Italy, France, Spain and adjoining countries, which were once part of the Roman Empire, and these are evidence of their high state of civilization. For 440 years after its founding or until 313 B. C., Rome was dependent for its water supply on wells and springs, but in the following four centuries nine aqueducts were built, and five others at a later period. Agrippa, who married the daughter of Emperor Augustus, was the first regular superintendent of the water supply of Rome, being installed 34 B. C., and in addition to building and extending the water system, he constructed many other public works. Masonry aqueducts of a similar kind had previously existed in other countries, probably in Greece, but not before had they been so extensive or of so permanent a character.

142. Julius Frontinus or Sextus, who lived 35 to 104 A. D., was a later engineer and superintendent of the water works of Rome, and he was a great builder and leader as well as a historian. He wrote two books on "The Water Supply of Rome" and six others on engineering subjects, some of which have been translated in recent times. The inability of the Romans to make pipes of sufficient strength to resist the water pressure which would result from laying them across the valley underground, may have been the reason for placing them on high stone aqueducts, for they must have known that water will seek its own level. The viaducts were built

with accurate grade, showing that they understood and used the level.

143. The nine aqueducts for the city of Rome were as follows:

(1) **Aqua Appia** was started by Appius Claudius, 312 B. C., who was also builder of the Appian Way, one of the great roads of Rome. This aqueduct brought water from springs, 10 miles distant and still running, but only 300 feet of it was on arches, the remainder being underground. It enters the city 60 feet above the sea level.

(2) **Anio Vetus** was built 272-264 B. C. Pont Lupo and other parts of this magnificent aqueduct are made of arches built of tufa and travertine. It brought water a distance of 43 miles from the river Anio and delivered it at the city 150 feet above the sea level, but only 1,100 feet is on masonry above the ground, the water way being 3.7 feet wide and 8 feet high.

(3) The **Martian aqueduct** was built by Quintus Martius, 144-140 B. C. It was about 60 miles in length, 12 miles of which was carried on masonry arches, and the original structure was so substantial that the two succeeding ones were built upon it. The material used was red, brown and yellow cut stone, 18x18x42 inches, laid in cement, and in some places, the aqueduct is 70 feet high, in three tiers, delivering water to the city 195 feet above the sea level. Having been reconstructed in 1869, it is still in use.

(4) **Aqua Tepula** was finished in 125 B. C. and brought water that was slightly warm, from volcanic springs in the Alban hills.

(5) **Aqua Julia** was built by Agrippa, 33 B. C.

(6) **Aqua Virgo**, completed by Augustus, 19 B. C., brought water from springs eight miles from Rome, which were only 80 feet above the sea level.

(7) **Aqua Alsientina** was completed by Augustus, 10 A. D., and took water from a lake twenty miles from Rome.

(8 and 9) **Aqua Claudius** and **Anio-Novus** were begun by Caligula, 38 A. D., and finished by Claudius, 52 A. D. These had brick and stone arches of 20-foot span, lined with concrete. Both aqueducts are carried on the same arches a distance of over eight miles across the Campagna, much of the viaduct being 105 feet above ground, and they are the highest in Rome. The whole length of the Anio-Novius is 62 miles.

Fig. 44.

144. **Pont-du-Gard** (Fig. 44) is an old Roman aqueduct built in the year 19 B. C., to supply water to the city of Nimes in France, a place which has many remains of ancient Roman civilization. It was built during the reign of Emperor Augustus, probably under the direction of Agrippa. There are three stories, the lower one containing six arches and the second story eleven arches of the same span, while the upper or third

has thirty-six smaller arch openings supporting the water-duct. The total length of the upper tier is 885 feet and its greatest height above water is 160 feet. In the year 1743, extensive repairs were made and the lower tier of arches was widened enough to carry a roadway on one side, so the present structure serves the double purpose of aqueduct and bridge, the length of roadway being 465 feet. The lower arcade was originally made of four separate rings, side by side not bonded together, and the second tier of three similar rings, the original width of the lower being 20 feet 9 inches, and the second and third tiers, 15 feet and 11 feet 9 inches, respectively. The largest central arch over the Garden river has a clear span of 80 feet 5 inches, while the adjoining ones on either side vary from 51 to 63 feet. The smaller arches in the top story have a uniform length of 15 feet 9 inches and all arches are semi-circular. The structure carries a single waterway 4 feet wide and 4 feet 9 inches high, and is built of cut stones tied together with iron clamps without cement excepting in the water channel on top. It is said to have been partly destroyed by the barbarians in the fifth century, but was soon repaired.

145. The **Metz aqueduct** is of Roman origin, before the Christian era, and has a single row of arches 1,000 feet long and 50 feet high. The Carthage aqueduct, 70 to 80 feet high, is carried on a long series of cut stone arches on piers 12 to 15 feet square, and the Mytilene and Lyons aqueducts date from about the same period.

146. The aqueduct of **Segovia** in Spain, was built by Emperor Trajan, 100 to 115 A. D. It is in two stories, 102 feet high at the center and has one hundred and nine arches, thirty of which are modern but similar to the old ones. The material is squared stone put together without mortar, and the total length of the structure is 2,500 feet.

147. The **Tarragona aqueduct,** similar to that of Segovia, is 100 feet high and 876 feet long, with two series of semi-circular arches, eleven in the lower and twenty-five in the upper story.

148. The aqueduct at **Antioch** has one bridge of rude design, 200 feet high and 700 feet long. It has a single row of uneven and varied arch openings in the upper part and a solid wall beneath with only two small openings.

149. Between the years, 109 and 310 A. D., five other aqueducts were built for the city of Rome, many miles of which were carried on masonry arches. There were, therefore, in the

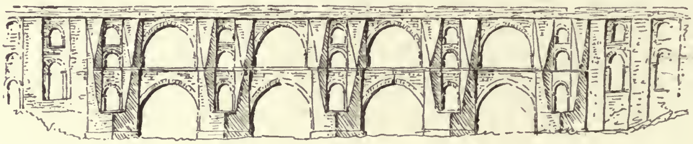


Fig. 45.

aqueducts of that city not less than 63 linial miles of stone arches, including the Alexandrina (226 A. D.). Remains of aqueducts at Mayence, 16,000 feet long, and others in Dacia, Africa and Greece are still extant.

150. The **aqueduct of Bourgas** near Constantinople is carried on a stone arch viaduct in two tiers, and was probably built during the reign of Justinian (560 A. D.). It is 109 feet high and 720 feet long, the arches of the lower tier having spans of 52 feet, while those of the upper tier are 40 feet. They are pointed, in both tiers, and the central piers which are strengthened with buttresses are pierced with minor arches. (Fig. 45.)

151. The aqueduct of Spoleto (741) in central Italy, 426 feet above the valley, was one of the highest masonry arch bridges (Fig. 18). It had ten tall openings 70.2 feet in the lower arcade, and thirty smaller ones above them, all pointed,

and the piers were 11½ feet thick at the springs. This account, given by Gauthey, does not agree with the present structure, which is only 250 feet high with ten openings in a single tier, the piers being wider than the adjoining spans.

152. The **Pyrgos aqueduct** near Constantinople, built subsequent to the tenth century, is in two branches at right angles to each other, with length of 670 and 300 feet respectively. The longer branch is in three tiers with a maximum height of 106 feet, the lower arches being pointed, while those of the two upper tiers are semi-circular. The width is 11 feet at the top, increasing to 21 feet at the bottom, and piers in the lower story have buttresses. The shorter branch contains twelve semi-circular arches.

153. The most notable bridge structure of the period in North America was the **Tempoalo aqueduct,** 1553-1570, seven miles south of Huauchinango, Mexico. It was built under the direction of the Franciscan Friars and contained sixty-eight semi-circular arches of stone, the largest being 58 feet. It was erected by Tembleque on two connecting tangents containing an angle of 177 degrees. The maximum height was 124 feet and the waterway very small, being only 8½x12 inches.

154. Another important stone aqueduct bridge in Mexico is one built for the city of **Queretaro,** in the years 1726 to 1735, by the Spaniards under Antonio Avana, with seventy-four spans of 50 feet each. The masonry is 92 feet high and it cost $125,000, of which $82,000 was donated by one person. Arches 3 to 4 feet in thickness are supported on stone piers about 10 feet square, which diminish from the springs to the width of the arch at the top. The water is conveyed from mountain springs five miles distant. Other structures of this kind in Mexico and West Indies are at Cuernavaca, Guadalupe and Orizaba.

155. The stone aqueduct of **Alcantara near Lisbon,** was projected from 1713 until construction began in 1731 from de-

signs by Mausel de Maya, but it was not completed until 1774. Its origin has been attributed to Trajan, but no more than the beginning was made in that day. There are thirty-five arches, pointed, the center one being 108 feet in span with a rise of 88 feet. The height is 227 feet and total length 2,464 feet. It carries the whole water supply for the city of Lisbon and successfully withstood the earthquake of 1775.

156. Others of about the same time are at Cazerta, Italy (1753), in the reign of Charles III., under the architect Vanvitelli, a beautiful work in three arcades, and Montpelier, France (1750), by Pitot, chief engineer of Languedoc. Mr. Telford built several aqueducts in England and Scotland, including the Chirk aqueduct of the Ellesmere Canal over the Ceriog river (1802) and the Cyssylte. Both of these were partly of cast iron, the first having a bottom lining, and the latter, a complete iron channel, supported on cast iron arch ribs between stone piers.

157. The Manhattan water supply is brought into the city of New York in pipes on a series of stone arches known as land, including the Chirk aqueduct of the Ellesmere Canal over **High Bridge** (Fig. 36), a part of the Croton aqueduct. A tunnel under the river was not desired and the high bridge was adopted instead. The demands of navigation made it necessary to provide a clear head room of 100 feet beneath the bridge with openings of not less than 80 feet in width. There are therefore eight spans of 80 feet over the water, with six spans of 50 feet at the end next the main land, and one span of 50 feet at the end adjoining Manhattan Island. The total length of bridge is 1460 feet and height of parapet above the high water 116 feet. The width is 21 feet over parapets and the entire faces of the spandrels and piers batter out on each side at the rate of 1 inch in 4 feet. The bridge originally carried only two lines of cast iron water pipes, 36 inches in diameter,

but a third line, 90 inches in diameter, was added later. At high water the river had a width of 620 feet. The deck carries a driveway and two footwalks, guarded by light and ornamental railings. Above the arches the bridge is relieved with belt courses and a coping supported on corbels, and at the piers are pilasters extending from the arch springs to the copings, the whole giving a very pleasing and satisfying effect. The design and construction was under the direction of John B. Jervis, Chief Engineer of the Croton Aqueduct, and the erection took place during the years 1837 to 1842, at a cost of $737,800. The Mohawk river aqueduct at Crescent, N. Y., designed by W. J. McAlpine, was constructed during the years of 1838 to 1842 and contained twenty or more spans having a total length of 1137 feet.

158. The **Roquefavour Aqueduct** near Aix, France, over the Arc river on the canal from Durance to Marseilles, is a masonry arch structure 1,290 feet long and 270 feet high, forming part of a conduit of 57 miles by which water is supplied to the city of Marseilles and its suburbs from the Durance river. It is 48 feet wide at the top, the canal being 22 feet in width at the bottom. Like Pont du Gard, there are three arcades, the lower one having twelve arches of 49.2 feet, the middle one fifteen arches of 52.5 feet and the upper 52 arches of 16.4 feet. The Roquefavour is a fine example of recent stone arch aqueducts, being built during 1841 to 1847, and it was for many years the highest stone bridge in France.

159. Prior to the building of the High Bridge, a stone aqueduct was commenced at **Rochester,** N. Y. (1820), to convey water over the Genessee river, and was built of red sandstone with eleven arch spans in an entire length of 802 feet. One at Washington over the Potomac was started in 1837, with seven arch spans, contemporary with the building of the Croton aqueduct bridge. The present water supply for Washing-

ton is carried over the **Cabin John bridge** (Fig. 37), built by General Meigs in 1857 to 1864. The span of 220 feet was the longest masonry arch for many years. The roadway, with a width of 20 feet over parapets, is 101 feet above the water. The arch is a segment of 110 degrees, with a rise of 57 feet, crown radius of 134 feet and a granite arch ring, 4 feet deep at the crown and 6 feet thick at the springs. The spandrels are of sandstone and the backing behind the arch ring is laid with radial joints, thus adding greatly to its strength. The entire work is very simple in character, the flatness of the face being relieved by two projecting courses at the parapet. Another notable aqueduct bridge (Fig. 38) is at Newton Lower Falls, Mass., having been built by the Boston Water Commission in 1876, under Mr. Fitzgerald's direction as Chief Engineer. It is known as **Echo bridge** and carries a conduit over Charles river, with one span of 129 feet, 42-foot rise and five other spans of 34 to 37 feet, at a height of 78 feet above the water. It is within the Metropolitan Park system, and though unsymmetrical in span arrangement, presents a very pleasing aspect in summer, with the smaller spans screened by trees and shrubbery.

CHAPTER VII.

WOODEN BRIDGES.

160. There are few wooden bridges now standing, more than one hundred years old, all earlier ones having disappeared. The normal duration of those which were roofed over and protected from the weather was generally thirty to forty years, while the open ones without covering would last about one-third as long; but fires were so frequent, especially on railroad bridges, that many were burned before their timber was decayed. Wooden bridges which escaped fire had parts frequently renewed, and after many years might contain none of their original timbers. **Ikakuna bridge** (Fig. 29) over the Kintai river in Japan, with five arches, built in 1673, had one span renewed every five years, and the whole bridge was, therefore rebuilt four times every century. Pons Sublicius (Fig. 4) over the Tiber river at Rome, Caesar's bridge over the Rhine (Fig. 8) and Trajan's bridge over the Danube (Fig. 11) were all made of timber, and many others were doubtless built in ancient and mediaeval times, of which no account appears in history. The remains of an old wooden bridge, dating from the eighth century, were removed from the river bed of the Rhine in 1883. The old bridge stood on twenty-eight bents, but was struck by lightning and burned. The fifty piles which were taken out were in good condition after 1100 years. Truss bridges were unknown until the sixteenth century, when **Leonardo da Vinci** and **Palladio,** the Italian architects, invented and built wood truss frames for bridges and roofs which differ little from those used at the present

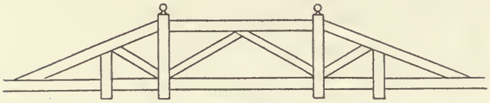


Fig. 46.

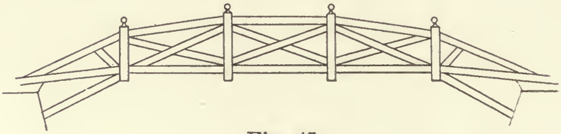


Fig. 47.

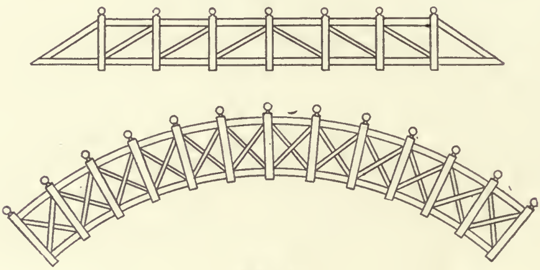


Fig. 48.

time. Some of the forms used by Palladio are illustrated in Figs. 46 to 48. He built a wooden bridge of five spans over the Brenta near Bassano (Fig. 49) and another over

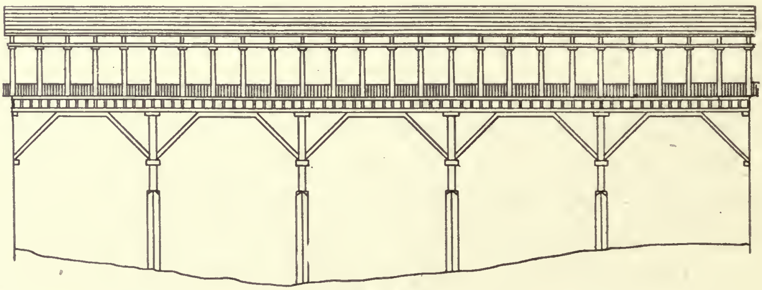


Fig. 49.

the Cismore at the same place with a span of 108 feet, but his truss discovery was forgotten and not rediscovered until the latter part of the eighteenth century, when Hale, Burr and others again used truss construction for timber bridges.

A wooden bridge on the Palladio principle with a span of 87 feet, 13-foot rise and 20-feet wide, was built at Walton Park, England, the country seat of the Marquis of Buckingham.

161. A curious but ingenious wood cantilever bridge at **Wandipore** in Tibet, built about 1650 with a clear span of 112 feet between shore towers, was made of fir, pinned together with wooden pegs, without iron of any kind. It had three separate roadways, with entrance gates and side railings, and lasted for one hundred and fifty years. Another old type over the Kandel (Fig. 50) in the canton of Berne, had one span of 166 feet, designed by Joseph Ritter.

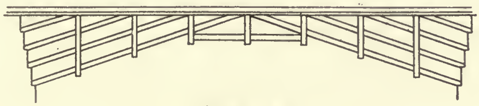


Fig. 50.

162. Prior to the nineteenth century, the size of framing timbers was determined by judgment or from the study of models and previous failures. Experienced builders became very proficient and their work showed much skill. The "Great Bridge" at Boston, Mass., built in 1662 on the site of the North Harvard St. bridge, between Brighton and Cambridge, was of timber on pile bents 15 to 20 feet apart, and was one of the earliest in North America, but the most interesting ones of the century were found in Europe. In 1738, a contract was awarded to John King for building the **Westminster bridge** across the Thames, to consist of thirteen timber arches, of 52 to 76 feet, on stone piers. Money for the purpose was raised by lottery, but after the piers were nearly completed the design was changed to stone arches according to a plan by Labelye. King's plan showed a length of 1164 feet, and a width of 44 feet, with arch timbers spreading out in fan shape from the piers. After the contract was signed and the

piers nearly completed, Labelye published a pamphlet showing how his design could still be substituted for the one with wooden arches, and circulated this pamphlet in England among the members of Parliament. He appealed to their pride, declaring that a wooden bridge across the river at the world's metropolis was a disgrace to the nation and out of harmony with the monumental buildings and wealth of London. Labelye's efforts were successful, for John King, being liberally paid, relinquished his contract and the stone arch was built with Labelye as engineer.

163. Several of the finest early bridges were in Switzerland, where good timber was abundant, one of these being at **Schauffhausen** over the Rhine (Fig. 51). It was built in 1758, at a cost of $40,000, by Ulrich Grubermann, an uneducated village carpenter of Teufen. It was 18 feet wide and had a clear length of 400 feet between abutments, but a central

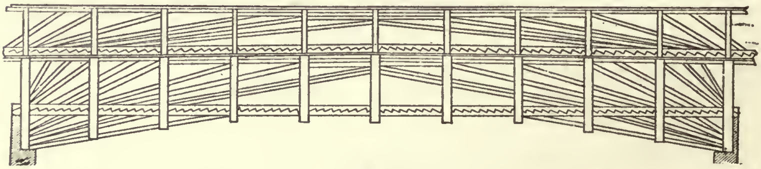


Fig. 51.

pier of a former bridge divided the bridge span into two parts of 172 and 193 feet. The arrangement of members and details was complicated, but they clearly show the intention of making the whole length in one span, though the inclined members to the center pier, probably inserted to gratify the skeptical authorities, who doubted its strength, also show provision for transmitting the loads to the central support. When completed, the bridge had very little bearing on the center piers, for pedestrians or other light loads would cause it to spring from the bearing, but heavy loads were safely carried for forty-two years. As the oak timbers, where they

rested on the abutments, were found to be decayed, it was repaired in 1783 by Spengler, and the whole bridge was temporarily supported on jacks while these timbers were being renewed. Several stone bridges on the site had previously been washed away, and this one, which occupied three years in building, was destroyed by the French in 1799. The bridge over the Limmat near the abbey of **Wittengen** at Baden was also designed and built by Ulrich and John Grubermann in 1758, and was burned by the French army in 1800. It had a clear opening of 390 feet and was the longest span wooden bridge ever built. A similar one 240 feet long was erected by John Grubermann at Ruichenau, and several years later the two brothers built another near Baden over the Limmat with a span of 200 feet, while others similar to the Schauffhausen were located at Landsberg and Zurich, the latter having a span of 128 feet.

164. A wooden bridge on thirteen piers, with a length of 270 feet, was built by Samuel Sewell over the York river, Maine, in 1761, and was rebuilt in 1793, but there are no complete records of wooden bridges in America prior to the Charlestown bridge over the **Charles river at Boston,** which was commenced in 1785 by Samuel Sewell and completed thirteen months later, at a cost of $50,000. This was the first bridge connecting Boston with the main land and succeeded the ferry which had been used since 1630, the new bridge remaining until 1899, when it was replaced by the present steel one. It was 42 feet wide, 1,500 feet long, with a 30-foot draw span, and was supported on seventy-five piers, 20 feet apart. Being a toll bridge for many years, it was very profitable, paying 30 to 40 per cent interest annually on the investment, and similar ones were built at Beverly and Malden in 1787. Three years later (1790) when a bridge was required at Londonderry, Ireland, the services of Eugene Lemuel Cox

of Boston were secured, and he erected one 40 feet wide, 1068 feet long, with oak piers 16½ feet apart, like that over the Charles river at Boston. A bridge at **Hampton Court,** England, 500 feet long, had seven timber spans, three on each side of a center draw, supported on six cribs filled with stone. In 1789, a 100 foot model for a bridge with a single span of 980 feet, to cross the Neva river in Russia, was made by an American engineer. It had four timber frames, two on each side, with suspended roadway. In 1792, the **West Boston bridge** over the Charles river was chartered and completed in the following year on the site of the present new Cambridge bridge. It was a wooden pile structure 3583 feet long and 40 feet wide, supported on one hundred and eighty bents, with a 30-foot draw span, the whole costing $76,000, but it was rebuilt in 1854 with a width of 50 feet and has been immortalized by the poet Longfellow.

165. A bridge at **Manchester, N. H.,** over the Amoskeag river, constructed in 1792 by Col. William P. Riddle, had six spans of 92 feet and a length of 556 feet, being completed in the short space of two months.

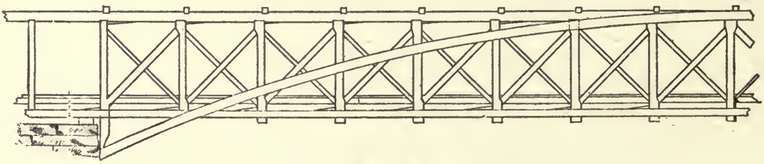


Fig. 52.

Among the **early American bridge builders,** the most prominent were Col. Enoch Hale, Timothy Palmer, Theodore Burr and Lewis Wernwag. Timothy Palmer built bridges at Essex, Andover, Portsmouth and Haverhill, N. H., the Georgetown bridge over the Potomac, the Easton bridge over the Delaware, and the "Permanent Bridge" at Philadelphia, while Theodore Burr built bridges at Waterford (Fig. 52), Fort

Miller, Trenton, Schenectady, Harrisburg and Philadelphia. Previous to the introduction of Mr. Burr's bridges, most long spans were some form of arch. The scientific building of wooden bridges in America dates back to 1792 when Col. Enoch Hale designed a bridge to cross the Connecticut river at Bellows Falls, Vt., with two spans of 175 feet and a length of 368 feet, the center pier being founded on a natural rock in the middle of the river. It was a combination of arch and truss similar to that patented by Mr. Burr a few years later. The Mellingen bridge with one span of 157 feet, built in Europe two years later, was somewhat like this, but was supported chiefly by the arch (Fig. 53).

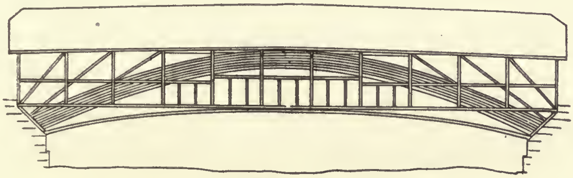


Fig. 53.

166. The **Essex bridge** over the Merrimac river at Deer Island, three miles above Newburyport, was built by Timothy Palmer in 1792 at a cost of $36,000, and was divided by the island into two parts. The part on the Newbury side was 483 feet long with three deck wood spans and a through truss of 160 feet in twelve panels, while the portion on the Salisbury side, 592 feet long, had one truss span of 113 feet and a bank approach, both spans having a clearance of 40 feet beneath. The piers and abutments were heavy timber cribs filled with stone, containing enough logs to reach 50 miles if laid end to end. The larger of the two spans was replaced in 1810 by John Templeton's chain suspension bridge, but the smaller span remained until 1833. Timothy Palmer built another bridge over the Merrimac river at Andover in 1793, which was rebuilt ten years later.

167. Between 1795 and 1800 a pile bridge about a mile long was erected across Cayuga Lake in New York state, on the road from Albany to Niagara, with two hundred and ten bents 25 feet apart, each containing three posts standing on the hard gravel bottom and connected with four sets of braces and girths. But the length of all previous spans in America was surpassed in 1794 by an arch in the Piscataqua river bridge, seven miles from Portsmouth, N. H. The whole bridge was about 2,400 feet long, composed chiefly of pile bents and short spans, but a portion between the two islands in the middle of the river over water 46 feet deep, was crossed by a single timber arch of 244 feet. It was designed by Timothy Palmer, the arch being similar to one built by Palladio, the Italian architect, in the sixteenth century. Three arch trusses or ribs, with a rise of 27 feet and 18 feet deep, supported a floor 38 feet wide, each rib having three concentric rings, the center one supporting the floor. An English writer refers to "a wood bridge over Portsmouth river in North America, with 250-foot span, built by Mr. Bludgett, something similar to those of Grubermann Brothers in Switzerland," particulars concerning which are not available.

168. Palmer's bridge at Haverhill with three arches of 180 feet and a 30-foot draw span, had piers 40 feet square "with defensive piers or sterlings extending above," patents being issued to Mr. Palmer in 1797. Another bridge at Holt's Rock betwen Haverhill and Newbury, 1000 feet long, built in 1795, had four arches and a draw span, but was destroyed by ice in 1818.

169. Over the Connecticut river at **Hanover, N. H.,** a timber arch was built, 1796, with a 236-foot span, copied after Palmer's arch at Portsmouth, some of the pine timbers being 18 inches square and 60 feet long. The roadway followed the line of the arch, being 20 feet higher at the center than at

the sides, and vehicles had difficulty in crossing it, but eight years after completion it collapsed from its own weight without warning. It was built by Rufus Graves, who, after making a failure as a clergyman and later as a merchant, tried civil engineering, but failing in that also, entered the army and afterwards became a physician.

170. Several wooden bridges in Scotland were erected by James Burn of Haddington, in 1803, including a deck arch over the Don, seven miles from Aberdeen, with a clear span of 109 feet and 18 feet wide. The arch frames were made of short pieces of timber acting as voussoirs, but stiffened by bracing in the spandrels. Another in Scotland was a **340-foot arch** foot bridge, 7 feet wide, in one span, built by Peter Nicholson, over the **Clyde at Glasgow** in 1803, on the site of the present Albert bridge.

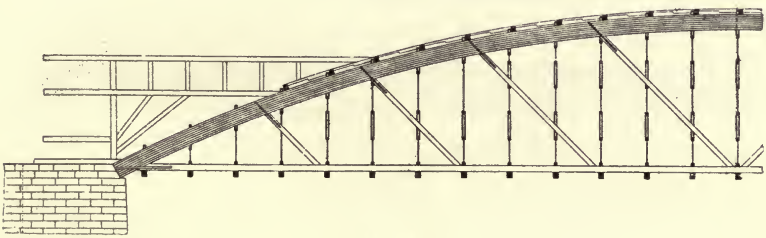


Fig. 54.

171. Two notable bridges in America built by Mr. Burr, were those at Waterford and Trenton. The **bridge at Waterford** over the Hudson (Fig. 52), built in 1804 of hewn yellow pine, was one of Mr. Burr's best designs. It remained uncovered for ten years after completion, but was then enclosed. It had four spans of 154, 161, 176 and 180 feet, and a total length of 797 feet, each span containing three lines of combined truss and arch on wooden piers. Two roadways 11 feet wide lay between the trusses, and the outside width was 30 feet. A similar structure was built by Mr. Burr at

Fort Miller over the Hudson. The Waterford bridge continued in use until 1909, when it was burned, and a steel truss with concrete floor was erected on the site. The bridge over the **Delaware river at Trenton** (Fig. 54) in 1804 had three spans of 161, 186, 198, and two of 203 feet. Each span had five through arch ribs with a rise of 30 feet, dividing the width of 36 feet into two carriage ways and two foot walks, and the roadway platform was suspended from the arch ribs at intervals of 8 to 16 feet by adjustable rods. The framing timber was white pine in lengths of 35 feet to 50 feet, and 4 inches thick, with joints staggered. The arch footings were renewed in 1832, and in 1848 the space occupied by the walk at one side was widened and used for a line of railroad, the inner trusses being strengthened, and the outer ones replaced by heavier ones. It was again strengthened in 1869, and replaced by an iron bridge in 1875.

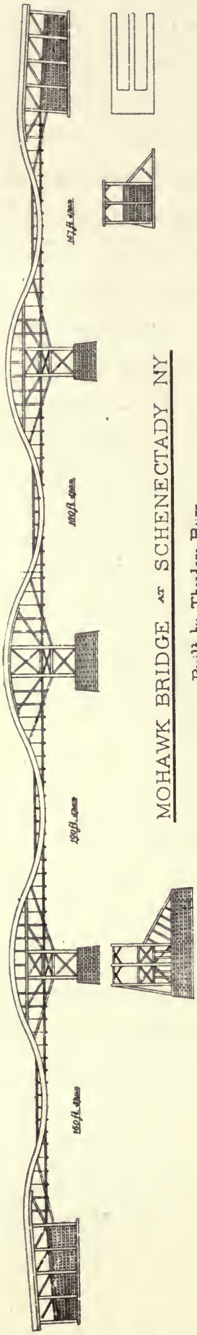
Fig. 55.

172. In 1777, when the English were in possession of Philadelphia, a pontoon bridge was built across the Schuylkill river at Market Street, which was replaced later by one of plank on floating logs. A new one, known as the **"Permanent Bridge"** (Fig. 55) was constructed by Timothy Palmer from 1801 to 1805, at a cost of $300,000. It had a central span of 195 feet with 12-foot rise and two side spans of 150 feet each, with 10-foot rise, the total length of framing being 550 feet, but as the abutments and wing walls were 750 feet long, the extreme length was 1,300 feet. It was covered and had three lines white pine trusses 20 feet deep at the center and 35 feet deep at the ends, with framing arranged to represent voussoirs.

The space between trusses was divided into two separate roadways, 13 feet wide, with an elevated sidewalk inside the outer trusses, making a total width of 42 feet. The carriage way had a camber of 8 feet, making the floor at the center 31 feet above the water. Piers were 20 by 60 feet at the top and were built in coffer dams, the depths of water being 24 feet at the east pier and 41 at the west. In 1850, the timber work was rebuilt from a different plan and the bridge widened for a car track. The Delaware river **bridge at Easton** built by Mr. Palmer in 1805, consisted of spans 163 feet clear and 195 feet center to center, and lasted for at least ninety years, only a small part of the original bridge being rebuilt. It had two lines of trusses 20 feet deep at the center, 34 feet at the ends, 27 feet apart and was enclosed. It was replaced in 1896 by a steel cantilever designed by Madison Porter.

173. Two timber arches in Germany, one over the Isar at Freysingen, and the other over the Regnitz at Bamberg, had spans of 153 and 208 feet respectively. Two sets of curved ribs, one above the other, were sheathed over on the face and painted to represent voussoirs. The framing timber was preserved by coating with oil and tar. A stone bridge formerly occupied the site of the Bamberg bridge, but its numerous piers so dammed the water that it was washed out, after which the timber arch was erected with a single span.

174. The bridge over the Connecticut river between **Woodsville and Wells River,** Vt. (Fig. 56), had a single span of 239 feet and carried a highway on the lower chord and a single track of the Boston and Maine Railroad on top above the shingled roof. It was five times rebuilt in timber and finally replaced in 1903 with a steel bridge. The first one on the site was a pile bridge built in 1805 by Avery Sanders at a cost of $2,700, but it was destroyed two years later and immediately built again. It was washed out in 1812, and for



MOHAWK BRIDGE AT SCHENECTADY NY

Built by Theodore Burr.

Fig. 57.

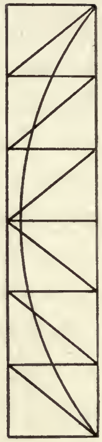


Fig. 58.

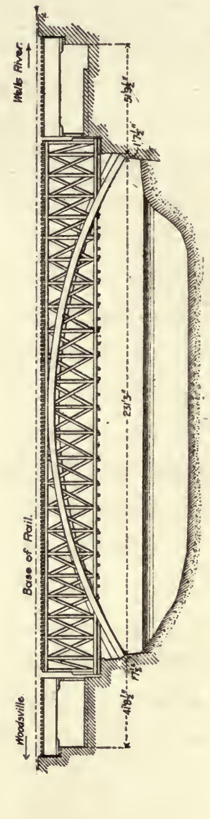


Fig. 56.

eight years there was no bridge, until in 1820, another which remained for thirty years was built at a cost of $2,585. The fourth bridge (1851) had timber trusses and wood piers, the fifth on the Burr type costing $20,000, was reinforced in 1868 and again in 1886, to carry the railroad on the upper deck. The timber trusses were 24 feet deep and 19 feet apart on centers, and the reinforcing arches had a rise of 30 feet.

175. The most unusual timber bridge in America was one over the **Mohawk river at Schenectady,** N. Y. (Fig. 57), built by Theodore Burr in 1808. It was a wooden suspension containing four spans of 157 to 190 feet, and was the second bridge on the site, the first one, which is said to have contained two spans of 450 feet, having collapsed during construction. In 1828, after twenty years' service, signs of weakness became evident and it began to sag. Piers were built under the center of each span, in which condition it remained until 1873, when replaced by an iron bridge. The curved ribs were made of eight layers of 4 by 14-inch plank spiked together.

176. **The Columbia bridge** (Fig. 58) over the Susquehanna river was built in 1812 at a cost of $232,000, but it was washed out in 1832 and immediately rebuilt at an additional cost of $157,000. It had twenty-nine timber spans 200 feet long of combined truss and arch without counter braces. The main braces and tie rods were in pairs and the upper chords were not continuous over the piers. It was burned during the Civil war (1863) to stop the troops from crossing, and in 1869 the old piers were purchased by the Pennsylvania Railroad Company, which rebuilt the bridge with Howe trusses, placing two iron spans as a fire guard in the middle. As rebuilt by the railroad company, the bridge had one 150 foot and twenty-five 198-foot Howe spans with two iron spans of 100 feet and one iron deck span 89 feet long, the whole having a length of 5,285 feet. It was destroyed again by a wind

storm in 1896 and was rebuilt in the following year in steel. The three span **bridge at Bethlehem,** Pa., which still remains (1910), is another of Mr. Burr's, the north span dating from 1816. The site was first occupied by a pile trestle, erected by Mr. Trucks in 1794 at a cost of $7,800. The truss bridge was not roofed over at first, and all spans remained intact until 1862, when the two south ones were washed out by a flood. It was immediately rebuilt and toll was collected until 1892, when it was purchased by the counties for $26,000 and made free. The trusses are wood lattice reinforced with timber arches, roofed over but open on the sides. The span lengths beginning at the North end are 125,110 and 135 feet respectively. It has a clear roadway of 18 feet, an outside width of 21.3 feet and trusses are 13 feet deep. Sidewalks were added in 1885. After a lapse of ninety-four years, this old wooden bridge is one of the best preserved of the early timber bridges, and stands in striking contrast to some of the newer metal ones in the vicinity.

177. The first bridge on the site of the old **"Long Bridge"** over the Potomac river **at Washington,** was built in 1809 at a cost of $100,000, but was destroyed by a freshet in 1831. The tolls collected were 25 cents for a man on horseback and $1.00 for a four-wheeled vehicle. Four years elapsed after its fall without a bridge, and in 1835 a wooden one was erected at a cost of $113,000. It was damaged in 1836 and again in 1840, but was re-opened for travel in 1843 and used to carry steam cars in 1867, and electric cars sometime later. In 1870, the Baltimore & Potomac Railroad Company secured it, keeping a highway open at one side, but the whole bridge was finally sold for the sum of $175, conditional on its removal. It had a length of 4,677 feet, divided into three section, the first 700 feet, afterwards filled in, followed by 1,980 feet of earth bank over the river flats. The bridge proper over the channel was

2,000 feet long, with thirteen fixed spans of 135 feet clear length and one pivot span of 182 feet. Of the three lines of trusses the two southern ones carrying the railroad were reinforced with timber arches. The clear width for the railroad was 19 feet and for the highway, 13 feet, while the total over all was 40 feet. Water several times rose two feet above the bottom chords and in 1905 it was replaced.

178. In 1811, Thomas Pope made a 50-foot model for a wooden cantilever bridge 1,800 feet long, to span the Hudson river at New York. He proposed building it with light timber frames from anchor cribs on either shore, and wrote and published a comprehensive description of his design.

179. Some of the finest bridges in America during the first part of the nineteenth century were designed and built by **Lewis Wernwag**, including those over Nashammony

Fig. 59.

Creek, the Colossus bridge at Fairmount, the New Hope bridge, costing $50,000 without covering, the Manoquay and Harper's Ferry bridges. The wood cantilever over Nashammony Creek of 1810, which had a movable panel at one end, he called "Economy Bridge," claiming that it could be used for spans up to 150 feet; but his largest bridge was **the "Colossus"** (Fig. 59), over the Schuylkill river at Fairmount, Philadelphia (1812). It was destroyed by fire in 1838 and was succeeded by Col. Ellet's wire suspension bridge, on the site now occupied by the Callowhill truss bridge. It was an arched truss with a rise of 38 feet and clear span of 340 feet, the same length as the Clyde bridge at Glasgow (1803), and up to that time was the longest wooden span in America,

though since exceeded by one in Oregon. Five curved wood frames 20 feet deep at the center, acted as truss and arch, with two roadways and two sidewalks between them, the bottom chords being composed of three sticks 6 by 13 inches. The east abutment stood on rock, the west abutment on piles driven to rock, and the whole bridge was roofed over and enclosed with sheathing. After completion it was tested by passing over it a wagon loaded with a stone weighing 22 tons and drawn by sixteen horses. This was Mr. Wernwag's third bridge, but between 1810 and 1836 he built about thirty others, the last being over the Potomac and canal at Harper's Ferry. Both the Permanent bridge at Market Street (1805) and the Colossus (1812) were somewhat like Thomas Paine's Wearmouth model for cast iron, made in 1787. In 1816 the Smithfield Street bridge at Pittsburg was built with eight spans of 188 feet, but was burned in 1845.

List of Mr. Wernwag's Bridges:

Name.	Date.
Nashammony Creek	1810
Bridesburg	1811
Colossus	1812
New Hope	1813-1814
Reading, Pa.	1815-1816
Monongahela and Allegheny, Pittsburg	1816
Wilkesbury	1817
Falls of Schuylkill	1817
Conneswingo on the Susquehanna	1818
Jones' Falls, Baltimore	1818
Brandywine Creek near Wilmington	1820
Paulding's Ford on Schuylkill	1823
Harper's Ferry	1823
Goose Creek, London County, Va	1824
Gunpowder Creek, Va	1824

Monoquay river near Frederick City	1827-1830
Port Deposit	1827-1830
Cambridge, Ohio	1827-1830
Monoquay Railroad bridge, B. & O.	1830
Romney, over South Branch of Potomac	1834
Harper's Ferry, over Potomac and canal	1838

180. Previous to 1816, only fourteen bridge patents had been granted by the United States. In 1820, an architect of New Haven, Ithiel Town, invented and patented the **Town truss** (Fig. 60), so many of which in spans up to 220 feet have

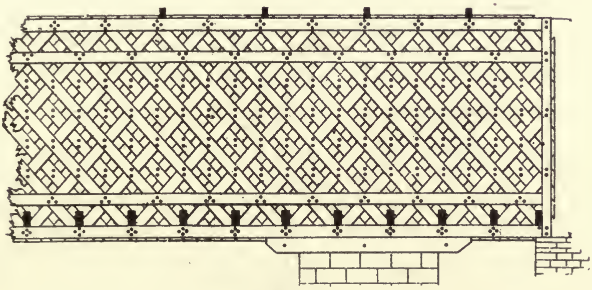


Fig. 60.

been used all over the continent for both railways and highways. The top and bottom chords were made of two or three parallel timbers and the web, of diagonal planks spiked together with wooden pins. They were made with uniform sections and were frequently continuous over the piers. Mr. Town published a pamphlet in 1831, describing his designs, claiming that these bridges could be quickly made from common plank, could be covered and protected from the weather and produced no overturning thrust on the piers, and the parts could easily be inspected for dry rot. His first bridge was on the New Haven and Hartford turnpike over Mill river near Lake Whitney, a suburb of New Haven. It was 14 feet wide, 12 feet high and 100 feet long. In later years this truss became

a prototype for iron lattice bridges, such as those at Kiel and Hamburg. An objection to the Town truss was its liability to twist and warp, owing to the thinness of the web and the lack of enough verticals near the end. This warping tendency is well illustrated by the old wood lattice bridge over the Jordan river at Salt Lake City, built under the direction of Brigham Young, which was renewed in 1908. It was recently examined by the writer and designs prepared for a new one. An improved form of lattice truss was therefore evolved which used a less number of a larger web members, the inclination of which changed from 45 degrees at the center, to vertical over the piers. Previous to 1820, most large spans had been some form of arch, but soon after this numerous wood trusses were invented, most of which were a combination or arch and truss with one or more systems.

181. In 1824 the Mill Dam bridge was built at Watertown, Mass., and four years later the Warren toll bridge over the Charles river at Boston. Tolls were discontinued on the latter in 1836, whereupon the owners of the Cambridge (Craig's) bridge removed the draw span and closed up theirs for five years. Both were again subject to toll in 1841, but in 1843 were thrown open to free travel.

182. In 1830, **Col. Stephen H. Long** of the U. S. Engineers, took out patents on a timber truss connected with wooden pins, and 1836, he published at Concord, N. H., a pamphlet of seventy-five pages describing it. The top and bottom boards were in three pieces, with double web posts between, fastened with wooden keys. The skew blocks between the web members and chords were made of oak or other hard wood, instead of iron, as on some later ones. The first bridge on his patent was on the Washington road two miles from Baltimore. Both the Town and Long trusses were often combined with an arch in long spans.

183. A wooden bridge, Pont Ivry, designed by M. Emmery (1828), crossed the Seine near Paris, with five arch spans, the maximum being 78 feet, and it remained until 1881, when replaced by metal.

184. In 1831, a timber street bridge was built by Robert Stephenson between the Broomielaw and old Glasglow bridges, over the Clyde at Glasgow. Fourteen spans of 34 feet each were supported on timber bents with flat knee braces from

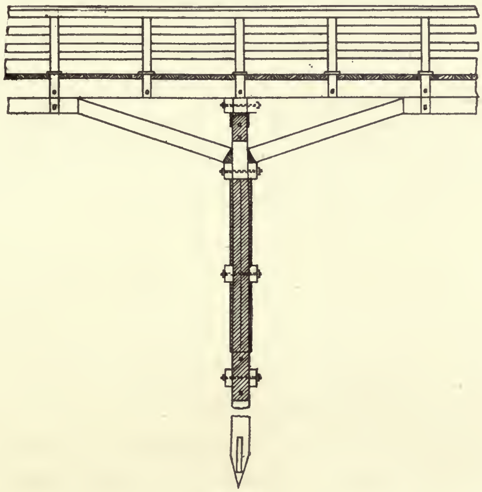


Fig. 61.

the bents, forming arch frames beneath the floor (Fig. 61). Another by Mr. Stephenson was the foot bridge at Abbey St. Bathans over Whitadder river, and one by William Bull over the Calder and Hibble Navigation.

185. In America the progress of bridge building was slow until the **introduction of railroads** in 1829, which gave an impetus to this branch of engineering. The first wooden railroad bridge in America was built by Wernwag for the Baltimore & Ohio Railroad at Monoquay in 1830. In 1834 the **Columbia covered bridge** over the Schuylkill river at Phila-

delphia was built for the Columbia Railroad, afterwards sold to the Philadelphia & Reading. This was the work of Mr. Burr and continued in use for fifty years, when it was replaced by one of iron. Another bridge over the **Susquehanna,** about five miles from **Harrisburg,** similar to the Columbia bridge, had counter braces and was more rigid. It had twenty-three spans of 160 feet, with trusses 18 feet deep and 20-foot arch rise. There were two lines of trusses and a covering, a single line of railroad being on the deck. During erection, after fourteen spans were placed, a violent windstorm blew six spans completely off their piers.

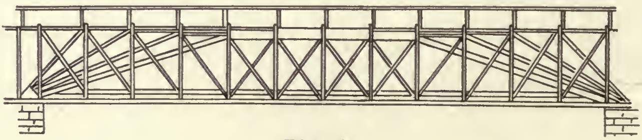


Fig. 62.

186. The Cumberland Valley Railroad **bridge over the Susquehanna** river at Harrisburg, with twenty-three spans of 170 to 180 feet, built at a cost of $62,000, was used until 1844, when all but four spans were burned. It was 4,277 feet long and had four lines of double lattice trusses, with two highways on the level of the lower chord and a single line of railway on top, and was rebuilt after the fire and roofed over. The old Long bridge over the Potomac at Washington, which was destroyed in 1831, was rebuilt in 1835 as previously described.

187. The Baltimore & Ohio Railroad built a number of wooden bridges, among which are the covered ones over the **Patapsco river** near **Elysville** (Fig. 62), eighteen miles from Baltimore. They were designed by Benjamin H. Latrobe in 1838 and patterned after the Schauffhausen bridge in Germany, but had counter braces and were more rigid. One of them had two spans of 150 feet on stone piers, while another over the

same river near by, had three spans of 110 feet, the two bridges costing $140,000.

188. In 1834 a single span bridge was built by General John Milroy over the Whitewater river at Richmond, Indiana, with three white oak arch ribs and light trusses. It was roofed over but open on the sides and carried two roadways and two walks outside the trusses. In 1897 it was found to have sagged five inches and was renewed.

189. A Town truss railroad bridge, over the James river at Richmond, Virginia, was built in 1838 with nineteen timber spans of 130 to 153 feet on granite piers, 4 by 18 feet at top, and standing 40 feet out of water. It had a length of 2,900 feet and was erected by Moncure Robinson at a cost of $125,000. The truss was 26 feet deep and the roadway on top was 60 feet above water. A similar Town truss bridge, over the Susquehanna river, had 220-foot spans and a length of 2,200 feet. Other similar trusses were at Nashua, Newburyport, Providence, Philadelphia and Trenton and one near New York on the Harlem river railroad 736 feet long, four near Troy, and one for the Baltimore & Ohio Railroad near Philadelphia.

190. A timber bridge of eight spans over the Seine at Eauplet, near Rouen, France, for the Rouen and Havre Railroad, was built by Joseph Lock with a length of 1,148 feet. Each span was 133 feet long and was supported by four timber segmental arches with a rise of about 20 feet, on stone piers. It had a width of 24 feet and carried two tracks, costing about one-third that of stone arches.

191. In the United States, Herman Haupt secured a patent in 1839 for a bridge truss, and the following year, William Howe was granted a patent on a truss (Fig. 63) with timber diagonals and vertical iron ties in single or double systems. Many **Howe truss** spans are still in use, and in regions where

timber is plentiful this type is extensively used on new roads for temporary work. Mr. Howe's first bridge was in 1840, and the second one completed during the same year, carried a railroad over the Connecticut river at Springfield, with seven spans of 180 feet. It lasted for thirteen years, when it was replaced by another Howe bridge which remained until 1874, when it was removed for a double track wrought iron structure.

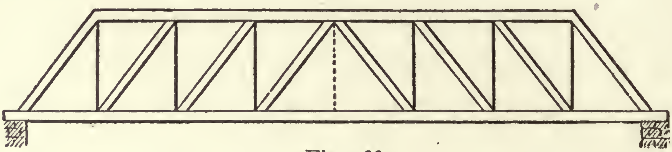


Fig. 63.

192. In 1844 Caleb Pratt invented and patented a truss (Fig. 64) similar in outline with the Howe truss, but differing from it in having the vertical web members in compression and the inclined diagonals in tension. This type was little used in wooden construction, but later became the prevailing one for trusses of iron and steel. Patents for timber trusses were also granted in 1851 to D. C. McCallum.

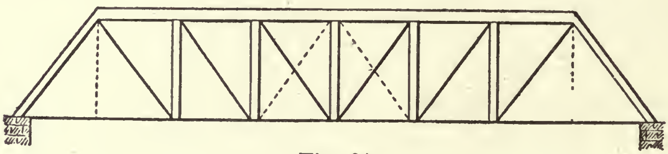


Fig. 64.

193. In the early days of railroad building in England many timber viaducts were built, one for the Newcastle, North Shields & Tynemouth Railroad over **Willington Dean** (Fig. 65) being typical of many others. The one mentioned consisted of seven timber arches of 115 to 128 foot span between stone piers, the height being 82 feet and length 1,048 feet. It was designed by John and Benjamin Green, engineers. Two similar bridges over Ouse Burn and Wellington Brook,

completed in 1839 stood until 1868, when the arches were removed by T. E. Harrison, engineer for the Northwestern Railroad, after building iron arches beneath them. The one over Ouse Burn had wood arches, 114 to 116 feet and four approach stone arches, a road 26 feet wide and a 5-foot walk on one side. A somewhat similar arch of one 275-foot span on the New York & Erie Railroad over **Cascade Glen** was built in 1848, from designs by Col. J. W. Adams. The chords have a rise of 45 feet and the deck is 25 feet wide and covered over, carrying a single line of railway in the middle. The

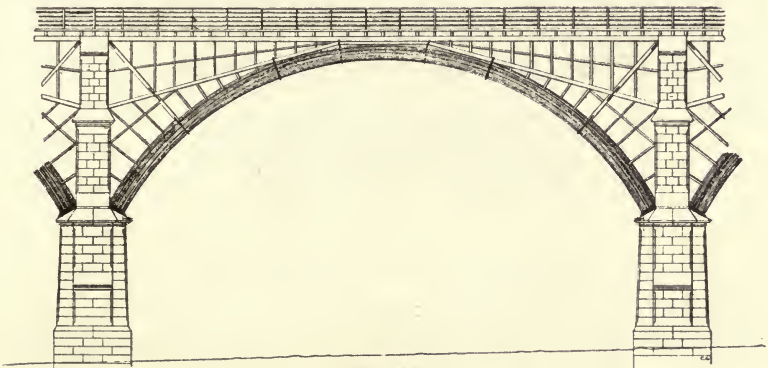


Fig. 65.

three timber hingeless arch trusses were 12 feet deep at the center and 11 feet 9 inches apart, the center truss being double width. The Glenury bridge in Scotland contained fourteen timber arches of 60 feet, between masonry piers, each span having six ribs.

194. The **Havre de Grace bridge** over the Susquehanna river on the Philadelphia, Baltimore & Washington Railroad contained thirteen spans of 250 feet and a draw of 176 feet, making a total length of 3,500 feet. It was completed in 1850 after five years in building at a cost of $2,000,000. The original bridge consisted of two lines of wood Howe trusses 20 feet apart, reinforced with arches carrying a single track, but was

replaced a few years later with an iron bridge, and again by the steel one in 1906. Many other bridges similar to this were scattered over the country. The usual practice was to remove the false work after the trusses were erected, allowing the whole dead load to be carried by them, and afterwards to place the arches. In course of time, as the bridge settled, the weight was finally borne by the arch, with the trusses only for stiffening.

195. A Burr truss of two spans, 148 and 154½ feet, carried the Pennsylvania Railroad over Sherman creek, and there was another at Clark's Ferry over the Susquehanna.

196. A railroad bridge over the Connecticut river between **Windsor Locks** and **Warehouse Point** (Fig. 66) was built in

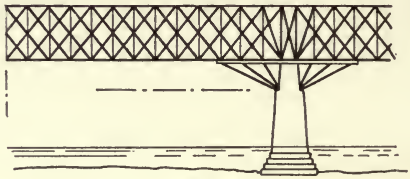


Fig. 66.

1844, with seven spans of 180 feet, one small span at the east end and three at the west adjoining the tow path and channel. It had a total length of 1,260 feet and carried one line of railway between the trusses, which were of the Long type. After two years the whole bridge was blown bodily off the piers in a violent windstorm, but a new one like the old was built in forty-five days, and it remained in use until replaced by one of iron in 1864. The clearance over low water was 29 feet, and it was supported on stone piers with radial braces from the piers spreading out at each side to the three lower panel points. George Washington Whistler (1800-1849), United States army engineer, was the designer, and a number of others similar to this were designed and built by him when engineer for the Petersburg & Moscow Railroad, all of which

were of timber. One over the Msta river had nine spans of 200 feet and a total length of 1,927 feet, carrying two tracks at a height of 101 feet above water. Three lines of wood truss 21 feet deep rested on piers, the upper 70 feet of which were timber on masonry bases. Two spans were burned in 1869 and replaced with steel.

197. An old highway bridge over Pine creek in Warren County, Ind., built about 1850 of **black walnut,** had a single span of 150 to 200 feet, and in recent years the timber became so valuable that several bridge companies offered to replace it in steel in return for the walnut.

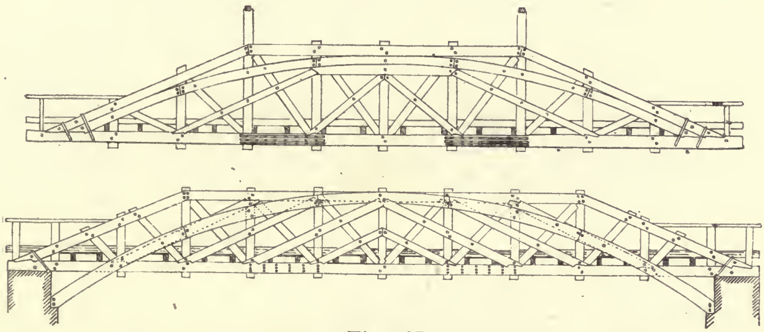


Fig. 67.

198. Two bridges on the Utica and Syracuse Railroad, made of plank and thin sawed timber in spans up to 100 feet, are illustrated in Fig. 67. The Kennebec river bridge at Skowhegan, Maine, had one span 124½ feet long, built in the middle of the last century and replaced by a steel bridge in 1904. It had two lines of combined truss and arch, 16 feet deep in centers, with a clear road 21 feet wide and 5-foot projecting sidewalks, the whole being roofed over but not otherwise enclosed. Immediately after its erection it showed signs of weakness and a suspension rod was inserted in each one to strengthen it. The floor supported on the bottom chord was 40 feet above the river, which was swift and deep.

199. Another covered wooden bridge of 1860 crossed the Delaware at Narrowsburg, N. Y., with a single span of 262 feet and floor 40 feet above the water. It was roofed over and

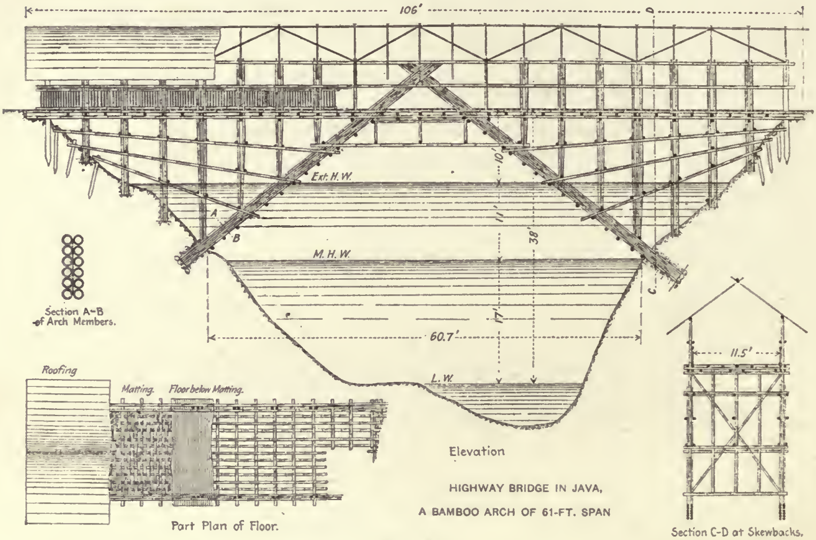


Fig. 68.

shingled and the lower part of its sides enclosed, leaving the upper part open for ventilation and light. The trusses were a combination of arch and truss of the Howe type.

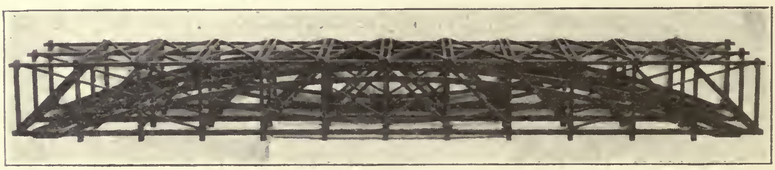


Fig. 69.

200. A bridge, designed by William Tyrrell of Weston, Ontario, the writer's father, to carry **King Street, Toronto,** over the river Don, had three lines of combined truss and arch (Fig. 69). The photograph is of a carefully made walnut

model, about 10 feet long, put together with brass bolts and pins, and, as far as known, is the only one of the kind.

201. A timber arch bridge (Fig. 70) for the Ladykirk and Norham Railway over the Tweed river, designed by John Blackmore, had two spans of 190 feet and 17-foot rise, on a

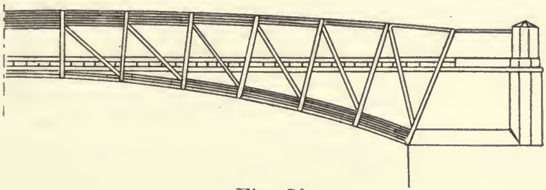


Fig. 70.

center pier 20 feet thick, carrying a road 18 feet wide. The timber frames which act as arch and truss had a lower chord, increasing in thickness towards the springs, and upper truss chords increasing in thickness to the center, with web posts radiating like parts of a voussoir arch. Another bridge, de-

Fig. 71.

signed by Mr. Blackmore for the Newcastle & Carlisle Railway over the Tyne at Scotswood, had eleven spans of 60 feet, 35 feet above low water, each span having trussed ribs supported on pile piers. Many other railroads in England and on the continent made extensive use of timber bridges. Five not-

able ones over the Aranyos river, on the Eastern Hungarian Railway, completed in 1870, had lengths of 650 to 1,150 feet, and a long pile and trestle bridge crossed the Danube at Vienna and Linz in the middle of the nineteenth century. **The Spreuerbrucke,** a covered wood bridge over the Reuss (Fig. 71) at Lucerne, Switzerland, built in 1871, is a picturesque example. Another very interesting timber bridge is one at Kanday, Ceylon, with an arch span of 205 feet and 20-foot rise, sup-

Fig. 72.

porting a deck 20 feet wide; it has four wood arch ribs of three double beams two feet apart. A triangular bamboo arch at Java, in the Dutch East Indies, is illustrated in Fig. 68.

202. Other typical wooden bridges in America are those at Grand Rapids, Minneapolis, St. Paul and Los Angeles. The Grand Rapids bridge carries Leonard Street over the Grand river (Fig. 72) and was built by William Seckel, city engineer, in 1879. It has eight spans of 104 feet each, the

trusses having six system Warren lattice, made of white pine and fastened at intersections with wooden pins. It lately showed signs of weakening by crushing over the piers, and in 1907 the whole bridge was strengthened by inserting additional vertical timbers at the supports and a system of diagonal rods, the work being carried on by G. J. Davis, Jr., under the direction of L. W. Anderson, city engineer. The Minneapolis Howe truss bridge (1873) crossed the Mississippi river with ten equal spans of about 160 feet.

203. A design was made by Tredgold (Fig. 73) for a 400-foot timber arch, and similar but smaller ones were erected at St. Paul and Los Angeles. The **Mendota ravine** near St. Paul is crossed by a single arch of 192 feet, carrying a deck 95 feet above the valley. It has two hingeless braced timber ribs, 15

Fig. 73.

feet deep and 18 feet apart, with 48-foot rise, the clear height beneath the intrados being 77 feet. A bridge somewhat like this may be found in Hollenbeck Park, Los Angeles, carrying a foot path high above the lagoon. A very interesting and unusual example of rustic bridge construction has recently been placed in the National Zoological Park at Washington, D. C. It is a **log arch** of 75-foot span and 30-foot width. In this wooded spot the rustic bridge corresponds well with the natural surroundings and produces a satisfying effect. The total length is 96 feet and the rise 11 feet. The cost, including macadam roadway and footwalk, was $3,000. Mr. Glenn Brown of Washington was the architect.

204. Small covered wooden bridges similar to Fig. 72 may still be seen in many parts of the United States, especially in the eastern portion of the country. One over the

McKenzie river near Coburg, Oregon, for the Southern Pacific, contains a span of 380 feet. The old covered bridge at Hartford, Conn., was burned in May, 1895, while a determined effort was being made by a local bridge building company to secure a contract for a new bridge at their proposed price of about $280,000. Finding themselves without a bridge

WEBSTER AVENUE BRIDGE, CHICAGO

across the river, the city of Hartford contracted for a temporary one of combined timber and steel, on pile piers, the drawing of which were made by the author. The contract called for its completion within two months time, and during this period communication was maintained by ferries.*

*Hartford Temporary Bridge. H. G. Tyrrell, in Railway and Engineering Review, August 31, 1901.

*Comparative Cost of Combination and All Steel Bridges, by H. G. Tyrrell. Scientific American, August 11, 1900. Indian and Eastern Engineer, April, 1901, etc.

CHAPTER IX.

CAST IRON BRIDGES.

205. Cast iron, though brittle and less reliable than steel, has the merit of little or no corrosion from rust, and bridges of this material are still in use, long after later ones of wrought iron and steel have been destroyed. Cast iron was favored also because of the opportunity for designing bridges which were light and ornamental with architectural features. The very earliest iron bridges were probably the chain suspensions in China and Japan of mediaeval times, but the first modern attempt at building one of cast iron was at Lyons, France, in 1755, when a single arch was erected at the foundry where it was cast. The effort was not successful and the project was abandoned as too expensive.

206. The most remarkable cast iron bridges were those designed by the English engineers, Rennie, Telford, Brunel and Stephenson, including the designs for bridges over the Thames and those projected for spanning the Menai Straits. In 1896, on the railroads of England and Wales (not including Scotland and Ireland), there were twenty-eight hundred bridges of cast iron, fifty-two hundred of wrought iron, fourteen hundred of wood and one hundred and twenty-one of steel. The cast iron were mostly girders, the longest being less than 50 feet, but the number show to what extent they were used previous to 1870.

207. In 1776 the cast iron bridge at **Coalbrookdale** (Fig. 74), over the Severn river between Medley and Brosely, near the town of Iron Bridge, was built by Abraham Darby at his

Coalbrookdale iron works, and in 1900 was still in good condition. It was designed in 1773 by Pritchard, an architect of Eyton Turret, who planned several large arches with clearance below for ships. It has one span of 100½ feet with five

Fig. 74.

segmental arch ribs nearly semi-circular, having a center rise of 45 feet, and at one end are two similar but smaller arches. Each rib has three concentric rings connected by radial pieces, and they were cast in halves, meeting at the center. It contains 378 tons of metal and was the first bridge in any country composed entirely of iron. The partial failure of the abutments and their movement forward from earth pressure behind them, caused the arch to rise slightly at the crown, giving it a pointed appearance. The English Society of Arts awarded a gold medal to Mr. Darby in 1788 for its construction. In the year, 1787, **Thomas Paine,** the versatile author and civil engineer, proposed building a cast iron bridge over the **Schuylkill river at Philadelphia,** with a span of 400 feet. He made models of the bridge in wood and cast iron and took the

wood model to Paris, where he submitted it with his plans to the Academy of Science for examination. As it was favorably received and found satisfactory for a span of 400 feet, Mr. Paine ordered two arch ribs of 90-foot span and 5-foot rise to be cast at the Walker foundry in Rotheram, Yorkshire, and tested them with double their own weight. As the tests were also satisfactory, he ordered, at the same foundry, the parts for a complete bridge with a span of 110 feet and the small rise of 5 feet, and had them shipped to London for a trial erection at Lisson Grove. Mr. Paine's project was, however, abandoned because of the failure of his financial associates, and the cast iron was taken back by the foundry to be used again in making the arch ribs for the bridge at Sunderland over the river Wear (Fig. 75). The designs for both the Coalbrookdale and the Sunderland bridges show that they were intended to act only as voussoirs arches, no reliance being placed on spandrel bracing.

208. The earliest iron bridge on the continent of Europe was at **Laasan, Silesia,** over the Striegauer Wasser. It has a single 60-foot cast iron arch with five parallel ribs, built in the years 1794 to 1796, soon after the completion of the one at Coalbrookdale, and was still in use in 1900.

209. Mr. Telford's first iron bridge was built in 1796, over the Severn at **Buildwas,** with a span of 130 feet. It had a width of 18 feet, contained 178 tons of iron and was cast at Mr. Darby's Coalbrookdale foundry, at a cost of $30,000. It was made with a small rise to better resist the earth pressure on the abutment and thereby avoid any accident similar to that which happened to the Coalbrookdale bridge. It was removed in 1906. Mr. Telford's best bridges were those at Tewksbury and Craigellachie, built about fifteen years later.

210. **The Sunderland bridge** over the Wear at Wearmouth, England (Fig. 75), was designed by Thomas Paine, patented

by Rowland Burdon in 1795, and built in 1796, under the direction of Thomas Wilson, who designed its architectural features. It has a single cast iron hingeless arch of 236 feet and 34-foot rise, and the roadway is 100 feet above the river. The six segmental arch ribs with open spandrels, the outer ones ornamented with circles, each had one hundred and five cast iron voussoirs like arch stones, 5 feet deep and 2 feet long, connected with wrought iron bars, supporting a deck 32 feet

Fig. 75.

wide, which was planked over and covered with gravel and limestone. It was cast from the metal in the discarded arches of the Philadelphia bridge, and contained 214 tons of cast iron, 46 tons of wrought iron, the cost, $135,000, being almost entirely donated by Mr. Burdon. In 1861 it was sold by lottery for $150,000. It was patterned after the model made by Thomas Paine for the Schuylkill river bridge at Philadelphia in 1787, and the Coalbrookdale and Sunderland arches, especially the latter (both of which act as voussoir arches), are the prototypes of many modern ones of wrought iron and steel. The bridge was widened in 1858-59 under the direction of Robert Stephenson.

211. In 1801 Mr. Telford and Mr. Douglas presented to the British Parliament a plan for rebuilding the **London bridge** with a single cast iron arch of **600-foot span** and 65-foot clear head room. Though it was referred to a committee of twenty persons no action was taken. In the following year Mr. Rennie proposed a single cast iron arch to span the entire width of **Menai Straits** at the site of the present Britannia tubular bridge, and at the same time made another design with three 350-foot arch spans and a center head room of 150 feet, both designs having many small approach arches at the ends, and he revised them again in 1810. In the years, 1810-11, Mr. Telford also prepared two plans for bridging the straits, the plan for one site having a single **500-foot span,** 40 feet wide, while the other site required three cast iron arches of 260 feet and two of 100 feet between piers 30 feet thick; but neither design was accepted. His **proposed Menai arch** had a center under clearance of 100 feet with 60-foot rise. He proposed erecting the voussoirs by means of a system of guy ropes or suspensions from the abutments. An aqueduct, Cys Sylte bridge, designed by him, located over the River Dee at the bottom of the vale of Llangallen, 1,007 feet long with nineteen spans of 45 feet and 126 feet high, has a cast iron canal box 5 feet high and 12 feet wide, supported on cast iron arch ribs and stone piers. It had a foot walk over the water at one side, with a substantial railing. The bridge over the Conway near Bettws-y-Coed (1815), also the design of Mr. Telford, bears an inscription in large open cast iron letters below the soffit, through its whole length, "This arch was constructed in the same year that the battle of Waterloo was fought."

212. A bridge over the Cam river at Cambridge, England, known as Gerrard's Hostel bridge, was designed by William C. Milne, son of Robert Milne, architect of old Blackfriars bridge, and was cast by the Butterfly Iron Company. It has

three ribs, a narrow roadway of only 9 feet and a span of 60 feet, slightly pointed, being patterned after Trinity Bridge in Florence. The railing was ornamental cast iron of Gothic design.

213. The earliest cast iron bridge in France was Pont-du-Louvre, with nine spans of 57 feet, built in 1803 for pedestrian travel. It was 30 feet wide, 516 feet long and each span had five arch ribs, the whole weight of metal being 263 tons.

214. **The Craigellachie** bridge over the Spey, by Telford, with a single span of 150 feet, was the first use of a cast iron arch with braced spandrel. It crosses the river where the road encountered a high bluff and makes a sharp turn. This and the bridge at Tewksbury are the finest cast iron bridges built by this distinguished engineer.

215. The Witham river bridge at Boston, Lincolnshire, and the Southwark bridge in London, were the work of John Rennie. The **Southwark bridge** over the Thames has three cast iron hingeless arches on stone piers 24 feet thick, the center arch being 240 feet and the two side arches 210 feet each, with rise of one-tenth the span, the arch rings being made in imitation of stone voussoirs. It is 710 feet long and each span has eight ribs in thirteen separate pieces 2½ inches thick, and 6 feet deep at the center. It contains 5,780 tons of metal and has the largest cast iron span ever built. In 1819, after five years in building, it was completed at the cost of $4,000,000. The widening of it is now (1910) being considered, at a prospective cost of $1,300,000. The Southwark and London bridges are Mr. Rennie's finest works.

216. The Monk and Hunslet bridges over the Aire river at Leeds, England, with single spans of 112 and 152 feet, built by George Leather in 1827 and 1832, were the first instances of a roadway suspended from overhead cast iron arches. A crossing of the Birmingham canal at Galton (1829) has parallel

chord lattice ribs and a deck covered with cast iron floor plates. A cast iron bridge was built in 1835 over Dunlap creek at Brownsville, Pa., by John Snowden of Brownsville, from a design by John Herbertson, with a span of 85 feet and width of 25 feet.

217. St. Peter's bridge over the Seine at Paris, known also as **Pont du Carrousel,** built during the years 1832-1838 by Polonceau, has three cast iron arch spans of 150 feet each, and a rise of 16 feet, each span having five arch ribs. The method of filling the spandrels with cast iron circles is not satisfactory or pleasing and will probably not be repeated in good designs. The length of bridge does not harmonize with the present condition of the docks, giving the impression of being too great for the location, and the piers are too thin.

218. The Thornby cast iron girder bridge over the Tees (1844) on the Stockton and Darlington railway, placed there by Robert Stephenson beside the old suspension, has five spans of 89 feet for double track. The girders of each span were in three pieces, bolted together and trussed with wrought iron bars, and all five spans were bolted together over the piers. After the failure of a similar bridge at Chester, each span was reinforced with inclined timber braces from the girders to the pier base, in which condition it remained until replaced by a steel bridge in 1906.

219. The Chester bridge over the Dee, which collapsed in 1847 a few weeks after completion under a derailed train, had three spans of 108 feet, with four lines of cast iron girders in two parts for double track. The floor, on which an excess amount of ballast had been piled, consisted of 4-inch plank over transverse timbers, resting on the lower girder flanges. The girder was 3 feet 9 inches deep, and the bridge was the largest of its kind.

220. In 1844 R. B. Osborne made about twelve combina-

tion cast and wrought iron girder bridges in America, with chords of wrought iron and intermediate braces of cast iron in the form of rectangular tubes.

221. The cast iron arch near Thirsk over the River Swale (Fig. 76), erected in 1847, carries two tracks of the Leeds & Thirsk Railway, and in 1908 was still in service. To lighten the dead load, an ornamental railing at the sides, together with a great accumulation of ballast, was removed about 1890.

222. When designing the **Britannia** and **Conway tubular bridges** in 1847, the engineers benefitted greatly by the surveys, reports and experience of Messrs. Rennie and Telford,

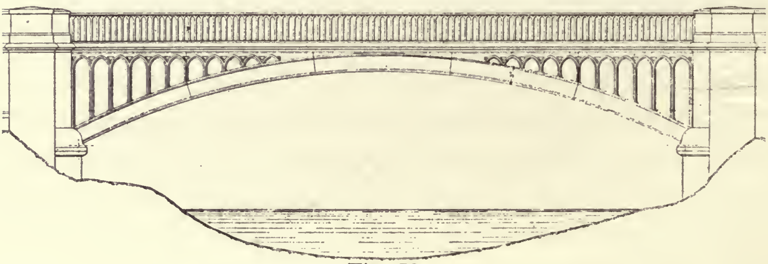


Fig. 76.

made more than twenty years before when they were designing the Menai suspension bridge. Mr. Brunel proposed two cast iron spans of 350 feet each, 105 feet above high water, for the Britannia bridge, and a similar 350-foot arch 20 feet above high water over the strait at Conway, and he developed a method of erecting them by cantilevering the voussoirs out symmetrically from the piers with corresponding arch blocks at each side, tied together over the piers with rods. The plan necessitated the use of half arches or anchor arms at the ends to balance the cantilever arms over the water, and showed that the arches could remain disconnected at the span center. The idea is doubtless the origin of the modern metal cantilever bridge, a similar principle being used twenty years later for erecting the arches of the Eads bridge at St. Louis.

Mr. Stephenson proposed two cast iron arches of 450-foot span, similar to Mr. Brunel's design, with 100 feet center clearance. The design was not accepted however, because the clearance which was sufficient at the center was diminished by the arch towards the springs, and the flat tubular bridge was used instead. Before proceeding with the construction, Mr. Stephenson ordered an elaborate series of experiments to be made on the strength of cast and wrought iron under the direction of two theoretical men, William Fairbairn and Eaton Hodgkinson, the conclusions from which, finally caused the abandonment of cast iron in favor of a more ductile metal.

223. Another bridge designed by Robert Stephenson in 1849 is that carrying three tracks of the Northeastern Railway over the Tyne at Newcastle. It has six metal spans of 125 feet, with two approach arches at one end and six similar arches at the other end, making a total length of 1,873 feet. Two platforms are supported by four lines of trusses in pairs, the upper deck carrying the railroads and the lower one the highways. The main spans are bowstring trusses with cast iron arch and top chords without diagonals, the arch thrust being resisted by lines of wrought iron tie rods at the lower roadway level. Piers and abutments are stone with a clear head room beneath the trusses of 83 feet. It contains 4,730 tons of cast iron in the compression members, 320 tons of wrought iron in the tension members and cost 243,000 pounds sterling.

224. The new **Westminster bridge** at London was built during 1854 to 1862 by Thomas Page, at a cost of $1,866,000, and replaced the old stone arch bridge of 1760, which had thirteen small arch spans. The design was made to harmonize with the architecture of the adjoining Parliament buildings.

225. The seven span cast iron arch bridge over the Neva at St. Petersburg, which was in use in 1890, was designed and

built in 1854 by Joseph Harrison, Jr. of Philadelphia. Two years later, Sir William Cubitt built a three-span cast iron arch at Rochester, England, over the Medway to replace the old stone one of the fourteenth century.

226. A very unusual bridge was completed over Rock creek at Washington, D. C., in 1859, to carry the **Washington aqueduct** from Georgetown. It consisted of two lines of cast iron water pipe 4 feet in diameter, through which the water flows, arched between the two abutments and supporting a highway and car tracks on a deck above. It has a clear span of 200 feet, a rise of 20 feet and was built under the direction of General Meigs of the United States army. The span is nearly as great as that of the Cabin John bridge in the near vicinity, which also carries an aqueduct, and their cost is an interesting comparison.

227. The site of the **St. Louis bridge** at Paris was originally occupied by an old suspension bridge connecting Isle St. Louis with Quay Napoleon. The present bridge, built 1860-62, has a single cast iron arch with a clear span of 210 feet, designed by M. Georges Martin of Paris, and built by M. Garnochot. The springs of the arch are 10 feet above low water and the arch has a flat rise of 19 feet, the total clearance beneath it at the center being only 29 feet. There are nine parallel girders about 6 feet 7 inches apart, the inner ribs being plain, 2 inches thick at the ends and 1½ inches at the crown, while the outer ribs are ornamental. The floor is laid on brick arches carried on cast iron beams 6 feet 7 inches apart, and the total width between parapets is 52 feet 6 inches, consisting of a carriage way and two sidewalks. It contains 745 tons of cast iron, and cost $137,000, and when built was the longest cast iron arch in France.

228. Duplicate cast iron bridges known as the Victoria and Albert bridges over the Severn river, England, were de-

signed by John Fowler and built in 1861. The Victoria bridge, located at Areley near Bewdley, carries two lines of railroad on arches, with a clear span of 200 feet and 20-foot rise. There are four main curved ribs or girders 4 feet deep, supporting a ballast deck on a solid plank floor 27½ feet wide, with clear head room beneath of 40 feet. Another small but ornamental bridge planned by Mr. Fowler spans the canal in Regent's Park, and is a model design for the location.

229. The largest cast iron bridge in America is at **Chestnut Street** in **Philadelphia,** crossing the Schuylkill river in the central part of the city, with two cast iron spans of 185 feet clear length. The distance between abutments is 390 feet and the total length over all is about 1,000 feet. The central pier was located in line with the west pier of the Market Street bridge. In addition to the central iron spans there are two stone arch approach spans at each end, of 53 and 60 feet respectively. The cast iron arch ribs are segmental and 4 feet deep, in lengths of 12 feet 10 inches, with a rise of 20 feet. The total width of bridge is 42 feet, consisting of a 26-foot road and an 8-foot walk on each side. The masonry is faced with cut granite and the original bridge cost $500,000, but in 1884 the foundations were underpinned and strengthened at a cost of $40,000 more. It was designed by Strickland Kneas, city engineer of Philadelphia, and built during 1861-66, its erection being seriously delayed by the Civil war. It adjoins the site of Thomas Paine's proposed 400-foot cast iron bridge at Market Street, but the Chestnut Street bridge has two spans instead of one as proposed by Mr. Paine. In place of a single span cast iron arch at Market Street, the river is crossed at this point by a wrought iron cantilever.

230. The El Kantara bridge over the Rummel at Constantine, Algeria, was designed in 1860 by M. Martin, with a center cast iron arch of 188 feet, two masonry arches at one

side and one at the other. It has five arch ribs carrying a highway 33 feet wide, over a ravine 394 feet deep and 414 tons of cast iron were used in its construction. The ornamental spandrels bear the letter "N," the initial of Napoleon. An ancient Roman bridge which fell about the middle of the nineteenth century, formerly occupied the site. Other cast iron railroad arch bridges in Algeria are over the Chiffa (1868) with four spans of 156 feet, over the Mina (1869) with one span of 146 feet, and over the Habra (1869) with two spans of 81 feet, all for single track.

231. Many other cast iron bridges of less importance were built during the nineteenth century, chiefly in England, where they were very popular. The old Blackfriars stone arch bridge at London (1760-70) with thirteen spans, was replaced in 1865 by five longer spans of cast iron, designed by Joseph Cubitt. It cost 270,000 pounds, and formed less obstruction to the

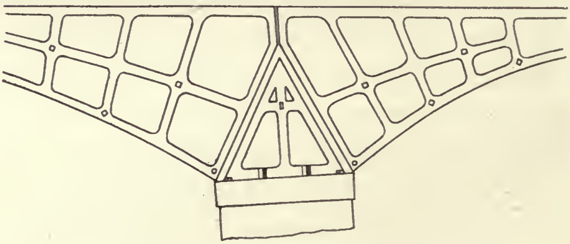


Fig. 77.

water and to navigation, but was widened in 1908 by Sir Benjamin Baker at an additional cost of 203,000 pounds sterling. Another notable bridge is that at Chepstow (Fig. 77), over the Wye, designed by Rastrick and Hazeldean, with cast iron ribs and wrought iron railing, and with one arch of 112 feet, two of 70 feet and two of 34 feet, the width being 21 feet.

232. The three span cast iron highway arch bridge over the Marne in France (1899) has center and side spans of $158\frac{1}{2}$ and 132 feet, with ribs 36 inches deep, 7 feet 3 inches

apart, and sections 13 feet 9 inches long. It has no crown hinge and the temporary ones at the ends were wedged up tight after erection. The stone piers go up to the grade and the floor has wood blocks on buckle plates.

233. Other important ones are those at Haddlesley, Yorkshire, over the Aire; Ely bridge over the Ouse; the Aberdeen, Staines, Bristol, Galton, Lary, Tees, Barnes and Nevers. Still others are the Tarascon, St. Denis, Austerlitz, Meuse, Lendal and the new Rochester (N. Y) bridge.

234. The introduction of ductile wrought iron and steel for structural purposes, following the experiments of Messrs. Hodgkinson, Fairbairn and Stephenson, from 1840 to 1846, and the failure of several cast iron bridges, led to a more general use of the former materials in preference to brittle metal, and in twenty-five years preceding 1900, not more than three or four cast iron bridges of any importance were built, the Eads bridge at St. Louis and the Alexander III. at Paris being cast steel.

CHAPTER X.

SIMPLE TRUSS BRIDGES.

235. The first attempt at building iron bridges was made in Italy in the middle of the sixteenth century, about the time that Palladio began using timber trusses, but no further record of them in that country appears until 1719. These bridges were used in Japan and China during the seventeenth century, two hundred years before coming into service in America, but authentic dates in those countries are not available, though their existence is certainly known. Malleable iron for other purposes has been used from very ancient times, for it is frequently mentioned in the Bible, as in Genesis, where reference is made to "artificers in brass and iron," B. C. 3875, and in Job, where letters "were graven with an iron pen," B. C. 1520. In Exodus 20-25 when building an altar, 1491 B. C., the use of tools was not permitted, and in the description of Solomon's Temple in Kings 6:7, which was erected 1014 B. C., it is stated that "no tool of iron was heard in the house while it was building." Iron tools and implements as well as helmets, chain armor, and other articles of iron, were found in the excavations at Nineveh. Methods of forging iron in ancient times are described by Homer (about 800 B. C.), but in modern times iron was first rolled into structural shapes in 1783 by Cort of England.

236. The first truss was probably a simple triangle, and from this, modern trusses with many connected triangles have developed. The first iron railroad bridge was a small one with four spans, on the Stockton and Darlington railroad (1823)

crossing the **Gaundless river** near West Auckland, England. The originator is supposed to have been George Stephenson. It somewhat resembled a modern trestle, for the spans were only 12½ feet long, supported on cast iron bents. The road was abandoned in 1856, and the bridge continued in use until 1842, but in 1901 was removed and placed on exhibition in the car shops at Darlington. Lattice trusses with a span of 84 feet were used by George Smart in 1824, for crossing the Dublin and Drogheda railway. His truss, known as "The Patent Iron Bridge," had vertical framing, and diagonals inclined at an angle of eighteen degrees to the vertical. But the first use of steel in bridge building was for the 300-foot suspension bridge at Vienna (1828), the eye bars being puddled steel. Fairbairn used riveted beams for the floors of buildings in 1832, and one year later the first American patent on an iron bridge was issued to August Canfield, but the **first iron girder bridge** in America was at **Frankford,** N. Y. (1840), over the Erie Canal with a span of 77 feet. The design was made by Earl Trumbull of Little Falls, N. Y., the cast iron girders being strengthened with wrought iron bars. It has been described as a combination of truss and suspension bridge.

In the same year, Mr. Whipple built his first bridge, a bowstring with cast iron top chords and wrought iron tension members, and a patent was granted to him in 1841, but in 1846 he adopted a trapezoidal form. The **first iron truss bridge** in the United States with parallel chords and open web, crossed a small creek near **Manayunk,** Pa., (1845) on the Catawissa branch of the Philadelphia and Reading Railroad, the design of Richard Osborne. He made three other similar ones 34 feet long and 3½ feet deep, with cast iron top chords and wrought iron in the bottom. The two tracks were supported between these trusses, which were fabricated by hand with-

out the use of machine tools. These bridges remained in use until 1901, though for many years they had been reinforced with timber bents. Patents were granted in 1846 to Frederick Harbach, on an iron Howe truss with cast iron braces and top chords, and wrought iron verticals and bottom chords, the chords and main braces being pairs of hollow tubes. A 30-foot span, 6 feet deep, with four panels, was erected near Pittsfield, Mass., on the Boston and Albany Railroad. A combination cast and malleable iron girder with parallel chords and multiple web system, similar to one used in France in 1844, was invented in 1846 by Mr. Rider of New York, and a patent was granted to S. Moulton. The bridge had T-shaped chords with wrought iron diagonals, which were connected to the verticals but not to the chords. The failure of one of these bridges in 1850 caused all similar ones on the road to be removed and replaced with timber, and after that time they were but little used.

237. The scientific and **exact computation of stresses** in bridge frames originated in 1847 with the publication of Squire Whipple's treatise, "A Work on Bridge Building," which was followed in 1851 by Herman Haupt's book, "The General Theory of Bridge Construction." These two books, written independently of each other, are the foundation of the modern theory of framed structures. Before that time bridge members were proportioned according to the judgment of experienced builders, which was often defective. One of the earliest double system Whipple bridges (Fig. 78) near Troy, N. Y., (1852) had a single span of 146 feet. The type as modified later by J. W. Murphy, and known as the Murphy-Whipple truss, continued in use until 1885. A bowstring of 187-foot span and 25-foot rise was erected in 1849 by Mr. Brunel, over the Thames at Windsor, for the Great Western Railway. Two other notable ones are the Newcastle high

level bridge over the Tyne (1849) and the Newark Dyke bridge over the Trent (1853). The **Newcastle bridge** (Fig. 79) carries the Northwestern Railroad over a ravine and river between the towns of Newcastle and Gateshead, on six spans of 125 feet, with four approach arches at each end, making a total length of 1873 feet, three lines of railroad being on the upper deck, and a highway and two walks at a lower level between the trusses. Piers and abutments are stone, allowing a clear headroom of 83 feet beneath the bridge. The four lines of bowstring trusses in two pairs have no diagonals, and 4,700 tons of cast iron were used in the compression members and 320 tons of wrought iron in the tension members. It was completed in 1849 at a cost of 243,000 pounds sterling, and officially opened by Queen Victoria. It was strengthened in 1894 and is still in use (1910). The transition of bridges in Europe was from stone to metal, and this partly accounts for the extensive use in European countries of cast iron arches and bowstrings, for which masonry arches were the prototype. But in America the change was more from wood to iron, and the early metal bridges here were modeled after wooden ones, though many lattice trusses were also used in Europe. **Newark Dyke bridge** carries two lines of the Great Northern over a branch of the river Trent near Newark. It is the earliest example of a Warren girder, and was erected in 1851-53 under Joseph Cubitt, from designs by Charles Wild. Four lines of trusses, two under each track, with cast iron pipes for compression members and wrought iron links in tension, have a clear span of 240 feet and a total length of 259 feet, the cost being 11,000 pounds.

238. Iron trusses of the Bollman and Fink type were extensively used on the Baltimore and Ohio Railroad from 1840 to 1850. Both types were of suspension truss form, without stress in the bottom chords, and frequently without any bottom

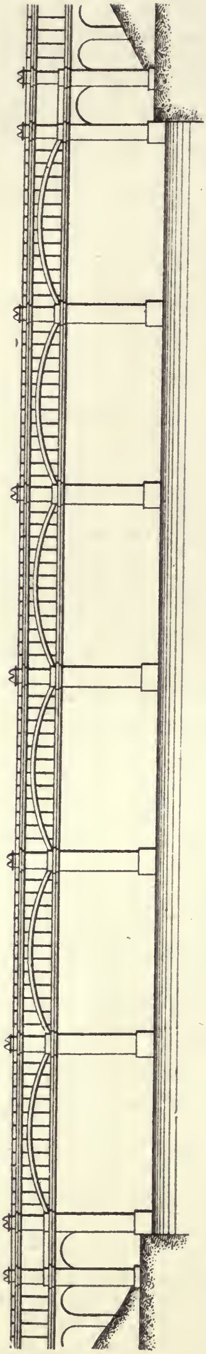


Fig. 79.

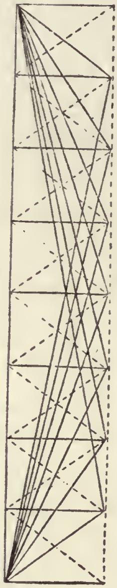


Fig. 80.

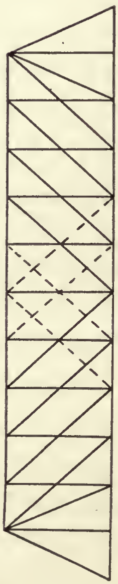


Fig. 78.

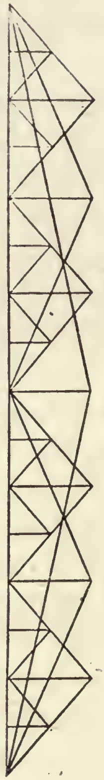


Fig. 81.

chords whatever, the **Bollman truss** (Fig. 80) having diagonal rods from each lower panel point to the ends. The Harper's Ferry bridge of 1852 with a span of 124 feet was of this type. Albert Fink, who was assistant to Wendell Bollman, invented and patented a new and improved form, and while the Bollman bridges were not long used, the **Fink type** (Fig. 81) continued in service until 1875. The first large Fink bridge (1852) crossed the Monongahela river at Fairmount, W. Va., with three spans of 205 feet. Both of these types had chords and posts of cast iron with wrought iron tension members. The first iron viaduct on the Baltimore and Ohio Railroad, which was all of cast iron excepting the tie rods, appeared in 1852, and in the same year, Pratt trusses were first built in iron. The Pratt truss (Fig. 64), invented in 1844, was at first framed in timber, but it has since become the prevailing type in iron and steel. One of the first firms to undertake bridge building in the West was A. B. Stone and L. B. Boomer of Chicago, who began business in 1851. With them were afterwards associated Edward Hemberle and W. G. Coolidge as engineers.

239. A Whipple bridge of 165-foot span over the canal at Phillipsburg, N. J. (1859), designed by J. W. Murphy for the Lehigh Valley Railroad, was the first pin connected truss bridge, pins being used instead of trunnions. It was removed in 1869 and placed in the center of a long wooden bridge at Towanda, Pa., as a safety provision in case of fire. A span of 152 feet over Saucon Creek on an uncompleted branch of the North Pennsylvania Railway, was never used and was afterwards removed. A bridge 89 feet high and 1,122 feet long in eleven spans (1857) was the first one designed by F. C. Lowthorp, who afterwards made many others.

240. Among the longest early truss bridges in Europe are the Chepstow (1852), with a 300-foot span, the Newark

Fig. 82.

Dyke (1853), with a clear span of 240 feet, and the Boyne viaduct at Drogheda, Ireland (1855), with a center span of 267 feet and two end ones of 140 feet.

241. The **Bessemer process** for converting steel was invented in 1855 and the Siemens-Martin process soon afterwards, and though Bessemer steel was used for a bridge in Holland in 1862, it was not favored nor again seriously considered for the purpose until 1880, when it was manufactured for the Forth bridge. Structural metal was having a wider use every year, and yet the great majority of bridges previous to 1860 were of timber. Twenty years later wrought iron was generally used, but before 1890 it was replaced by steel for eye bars, and in 1895 wrought iron was no longer rolled or obtainable in structural shapes, as it had been entirely replaced by steel.

242. **Metal lattice trusses,** of which the prototype was the American Town wooden lattice, became very popular in Europe, and many of this kind were built, including those at Dirschau (1857), with six spans of 400 feet, the Bommel bridge over the Waal with three similar spans, the Cologne bridge (1859), the Passau bridge over the Inn (1861), with a span of 420 feet, and the Berne bridge over the Aar (1857) with three spans on tall stone piers. The piers of the Dirschau bridge over the Vistula are continued above the metal work in the form of round battlemented towers. The Offenburg bridge over the Kinzig (1858) with a single span of 197 feet, has three lines of lattice trusses for double track, with heavy Gothic portal arches and a projecting foot walk on each side. **The Cologne bridge** (Fig. 82) crosses the Rhine east of the Cologne cathedral with four spans of 322 feet, making a total length of 1,362 feet. It carries railroad and highway travel in separate spaces with three lines of lattice truss in each span, and the floor is 47 feet above average water level. Over

the entrance at the Cologne end is an equestrian statue of William IV., by Blazer, while at the other end is a similar figure of William I., by Drake, erected in 1867. The bridge connects Cologne on the left bank of the river with Deutz on the right, and was built in the years 1855-59.

The **Kehl railroad bridge** carries two lines of the Baden State railroad over the river Rhine, about two miles from Strassburg, Germany, and was built during the years 1856-60 from designs by Keller. There are three main lattice girder spans of 197 feet each, continuous over the piers, and at one end are four additional spans of 85 feet and a draw. Each main span has three girders with single lattice webs and foot paths on brackets from the outer trusses. The bridge is 1,000 feet long and the Gothic portals at the entrance are fine examples of ornamental iron, the statues and crosses being suggestive of Gothic cathedrals. In ancient times the building of bridges was considered a sacred duty and the work was entrusted to an order of priests who were called "Pontifeces." It appears appropriate, therefore, that decorative features should perpetuate the memory and traditions of ancient bridge building.

243. Lenticular trusses of the Pauli system, on high stone piers, were used in 1857 in the three-span bridge over the Isar at Grosshesselote, but the best known one of the type is the Saltash bridge on the Cornish Railroad over the Tamar river near Plymouth (Fig. 83), designed by I. K. Brunel in 1859. **The Saltash bridge** has two spans of 455 feet with suspended roadway, and was the first through lenticular bridge. In addition to the two large spans there are seventeen smaller ones of 69¼ feet, making a total length of 2,240 feet. Each main truss was made complete on shore, floated out on pontoons and raised on jacks into position. The main piers are circular masonry, 35 feet in diameter and 96 feet high, and

the approach piers are double masonry columns 11 feet square, the rails being 100 feet above high water. The bridge is chiefly remarkable for having a single large tube as upper chord for both trusses. Over the end portals is the name of the engineer in letters four feet high. **The Mayence bridge,** similar in outline to the last, has four river spans of 345 feet and twenty-eight smaller ones. It crosses the Rhine between Frankfort and Mayence and carries two railroad tracks. The channel spans have four lines of light trusses with curved top and bottom chords, and the total length is 2,060 feet, and the weight, 600 tons. It was commenced in 1859, but in 1871 similar trusses were added to carry the second track.

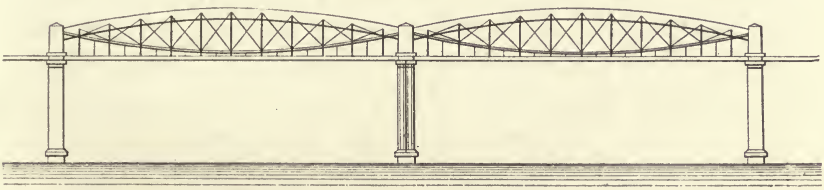


Fig. 83.

244. Wide **forged eye bars** were first introduced in 1861 by J. H. Linville in a bridge over the Schuylkill river for the Pennsylvania Railroad, though flat plate bars had previously been used in suspensions. The first bridges wholly of wrought iron, were riveted lattice girders with spans of 40 to 90 feet, designed in 1859 by Howard Carroll for the New York Central Railroad. In 1863 J. W. Murphy designed the first pin connected truss with wrought iron for both tension and compression members, to cross the Lehigh river at Mauch Chunk, on the Lehigh Valley Railroad, the only cast iron being that in the joint blocks. The first of the many long span bridges in America was at Steubenville, Ohio, over the Ohio river, with a channel span of 320 feet, four deck spans of 231 feet, and three of 205 feet, designed by J. H. Linville, who was after-

wards engineer on other bridges over the same river at Parkersburg and Cincinnati. **The Steubenville bridge** was replaced in 1889 and again in 1909. The Windsor Locks bridge over the Connecticut river (1866), designed by the American engineer James Laurie, is remarkable because the iron was manufactured in England by the William Fairbairn Company, and when erected in place cost $277 per ton, or more than twelve cents per pound. It replaced Colonel Whistler's old wood bridge of 1844, and was in turn replaced by a double track deck plate girder on the old piers.

245. Turning attention to Europe, the Runcorn bridge over the Mersey river near Liverpool for the London and Northwestern Railway, was commenced in 1863 from designs by William Baker, with three spans of 305 feet each, though there are one hundred and one openings in the whole bridge and viaduct. Beneath the channel span is a clearance of 75 feet for ships. Bridges at London with tubular piers are those at Cannon Street (1863-66), with heavy Doric columns, and the Waudsworth, Putnam, Blackfriars and Charing Cross bridges, the last two being completed in 1864. Blackfriars was built by Kennard, with three lines of lattice trusses for four railroad tracks, and clusters of pillars under each line of girders. The Charing Cross bridge, built from plans by Sir John Hawkshaw, at a cost of 180,000 pounds, was widened in 1882 under the direction of F. Brady. It replaced the Hungerford suspension, the piers of which were allowed to remain, standing out in contrast to the lighter ones. The Orival bridge over the Seine for the Western Railway of France, has six continuous lattice spans of 127 to 167 feet on cylinders 12 feet in diameter filled with concrete. The Mannheim bridge over the Rhine (1865-68) with three spans of 295 feet, connects Mannheim with Ludwigshafen and has space for railroad, highway and sidewalks, and the portals

designed by Durn, are adorned with groups of figures. The length of all previous truss spans was exceeded by that at **Kuilenburg** over the Leck river (Fig. 84), which has triple system lattice girders with curved top chords, designed in 1868 by G. Van Diesen. One span has a clear length of 492 feet, and

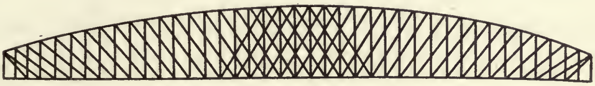


Fig. 84.

a total length of 515 feet, another span a clear length of 262 feet, and seven others are 189 feet long. A bridge design of unusual interest was made in 1867 by Carl Von Ruppert to cross the **Bosphorus,** with three lenticular spans, the center and two side spans having openings of 650 and 513 Austrian feet, and the project was again revived in 1890 and 1901. Alternate plans for a suspension bridge were also prepared by the American engineer John A. Roebling.

246. The first of **Mr. S. S. Post's patent trusses** (Fig. 85) was at Washingtonville (1865) on the Erie Railroad, but many others appeared in the next fifteen years, including those at Omaha, Leavenworth and Boonville. The lower end of the

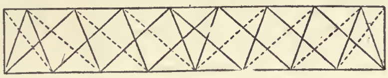


Fig. 85.

web posts were inclined half a panel length towards the ends, an arrangement which marred the regularity of the truss. The Omaha bridge over the Missouri river (1871), with eleven spans of 250 feet, 28 feet deep, on 8½-foot cast iron cylinder piers 140 feet high, was 2,750 feet long and cost $2,000,000. The Leavenworth bridge, completed a year later, carried both railroad and highway travel, 130 feet above the river. Two spans of 340 feet and one of 314 feet were supported on cylin-

der piers, the total cost being $1,000,000. But the combined railroad and highway bridge over the Missouri at Kansas City for the Chicago, Burlington and Quincy Railroad, first built in 1869 and reconstructed in 1891, is the oldest one over that river. It contains five fixed spans of 119 to 234 feet with parallel chords and a draw adjoining the right bank.

Two Mississippi river bridges were completed in 1868 at Dubuque and Quincy, the first having eight spans with a maximum of 240 feet, and the Quincy bridge eighteen spans of 151 to 250 feet and a 360-foot draw. The draw span is all of wrought iron, but the fixed spans are a combination of wrought and cast iron. The Louisville bridge (Fig. 86) over the Ohio river, for a single track, was designed by Albert Fink and finished in 1869. The largest spans are 400 and 370 feet and the draw span 264 feet, but there are also twenty-four shorter ones partly triangular and partly of the Fink type.

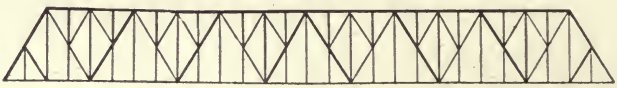


Fig. 86.

The track is above the trusses on all spans excepting the largest one, which has an under clearance of 90 feet above low water, or 50 feet above high water. The channel span was at that time the longest in America. Mr. Linville's two bridges over the Ohio at Parkersburg (1870) and Cincinnati (1872) contain long spans, the first, for the Baltimore and Ohio Railroad, having two channel spans of 350 feet, and forty smaller ones, the whole costing about $1,000,000. The Cincinnati bridge has a central span of 420 feet and twenty-three shorter ones, that over the channel exceeding by a few feet the corresponding one in the Louisville bridge. Mr. Linville designed many others, including one over the Connecticut river at Mid-

dletown with four spans of 200 feet and a central 300-foot draw, with a shore span of 54 feet at each end. An examination and report was made by the writer in 1896 for strengthening it (Railroad Gazette, August 2, 1901), but it has since been replaced by a heavier structure. The company for which Mr. Linville was engineer had, up to 1874, erected over twelve lineal miles of iron bridges, and nine miles of wooden ones. The combined railroad and highway bridge over the Mississippi at Hannibal, Mo., (1871) was the seventh bridge over the river below Dubuque. It was a low level structure with six fixed spans and a 362-foot draw, and cost, with approaches, $650,000, but was reconstructed in 1886. Another over the same river was erected by the King Bridge Company at Minneapolis in 1874, with a length of 1,100 feet, in six deck metal spans on stone piers, and the following year the same com-

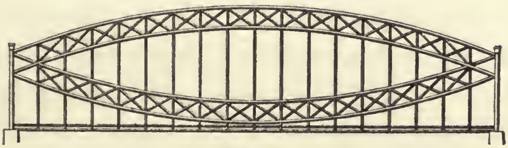


Fig. 87.

pany erected one at Topeka with six bowstring spans of 150 feet. The Atcheson bridge over the Missouri (1873-75) had three through fixed spans of 260 feet with parallel chord Whipple trusses, and a 365-foot draw at one end with projecting sidewalks. It was used by seven different railroads and had an 18-foot roadway which was floored over for highway travel, the whole work costing about $1,000,000.

247. The old Elbe river bridge (Fig. 87) at Hamburg (1868-72) with three lens-shaped girders of the Lohse type was widened in 1894 when a similar bridge was being erected at the same place. The upper and lower braced arches are connected with verticals without diagonals. Hamburg has two

other bridges over the Elbe, the highway bridge of 1887, and the railroad bridge of 1893, both of the Lohse type, the Gothic portals on the latter being very heavy and elaborate. The Stadtlau bridge over the Danube (1870) has fifteen spans, five of which are 249 feet long each. The Moerdyck bridge over the Holland Diep (1871), with fourteen spans of 328 feet, has double system trusses with curved top chords. The trusses are disconnected at the piers according to the usual practice in Holland, where foundations are too uncertain to permit continuity, but continuous girders are used on the large spans of the Danube river at Vienna, which has five openings of 262 feet and four of 112 feet.

248. Prior to 1860, the railroad companies designed their bridges in their own offices, and manufactured the parts in their own shops, but in the next ten years the men who had become proficient in designing, organized contracting and engineering companies and took contracts for manufacturing and erecting them, frequently on their own patented designs. These companies at first undertook work chiefly in their own districts, but competition was soon desired by the railroad companies, and prices were then asked on competitive plans. Until about 1875, plans continued to be made almost entirely by the bridge companies, who took lump sum contracts, a practice which tended to reduce the weight of metal to a minimum. These designs were prepared according to the railroad companies' **general specifications,** several of which appeared after 1870. Among these were the specifications of Clark, Reeves and Company (1891), the Erie Railroad by George S. Morrison (1873), The Cincinnati Southern Railroad by G. Bouscaren (1875), the Lake Shore Railroad by Charles Hilton (1877), the Chicago, Milwaukee and St. Paul Railroad by C. Shaler Smith (1877), and the Erie Railroad by Theodore Cooper (1879). Mr. Cooper's specifications were

afterwards adopted as standard by several companies, resulting in a greater degree of uniformity. Previous to 1875, engine loads were assumed uniformly distributed, but greater in amount than the accompanying train loads or a locomotive excess was applied to the train loads; but for twenty years after 1880 the actual loads on the locomotive wheels was used instead.

249. In the preparation for the Philadelphia Centennial of 1876, two bridges were erected across the Schuylkill river at Girard Avenue and Callowhill Street, 1874 and 1875. The **Girard Avenue bridge** adjoining the Zoological gardens is one of the finest examples of American city bridges. The abutments and piers show careful design and artistic treatment, though monumental features are absent. The three middle spans are 197 feet long, and each of the end spans, 137 feet, the whole having an outside length of 865 feet. The deck is 100 feet in width and on the roadway are eight refuge bays with clusters of six lamps over each bay. The outer balustrade and cornice are cast iron with bronze open work panels, and the roadway and sidewalks are separated by a lower but substantial railing. At the ends are steps leading down from the street to the level of the lower chords, where a sidewalk through the bridge is reached by arches in the abutment walls. At the abutments are drinking fountains, and the bridge is well lighted, there being in addition to the lamp clusters over the piers, intermediate lamps at the curbs. It was designed under the direction of Samuel Smedley, city engineer, and was completed at a cost of $267,000. The **Callowhill Street bridge,** finished a year later, with a span of 350 feet, was severely criticized because of the presence of artificial sheet metal facing representing arcades on the lower roadway, but this has since been removed. It has upper and lower decks and is a fine example of city bridge construction. The Falls of Schuyl-

kill bridge at Philadelphia is of more than usual interest because of its upper floor. The failure of an iron Howe truss in 1876 at Ashtabula, Ohio, with a span of 154 feet, in which accident ninety people were killed, resulted in discarding cast iron entirely by the railroad companies, and four or five years later it was also abandoned for highway bridges. The failure called attention to the need of better structures and shortly afterwards independent bridge engineers began practicing as specialists in this branch of civil engineering.

250. The Cincinati Southern Railroad bridge over the Ohio river at Cincinnati (1876), with a channel span of 515 feet, and a lower chord 106 feet above low water, was the largest simple span at the time, and the first to exceed 500

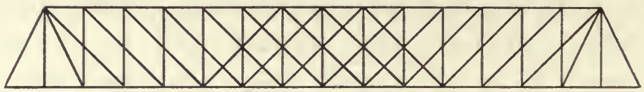


Fig. 88.

feet. It was designed by J. H. Linville, according to Mr. Bouscaren's specifications, and cost $700,000. The Smithfield Street bridge at Pittsburg, with two 360-foot spans, of the Pauli system, is the work of Gustav Lindenthal, and replaced Roebling's old eight-span suspension of 1845. Mr. Lindenthal's bridge was widened about ten years later by the addition of other trusses. The Glasgow and Bismark bridges over the Missouri river, and those at Henderson, Louisville and Cairo over the Ohio, all contain one or more long spans. The Glasgow bridge is notable for being the first all steel bridge in the world, but it was rebuilt for heavier loads in 1889-1901. The Bismark bridge (1882) (Fig. 88) was designed and built under the direction of George S. Morrison and C. C. Schneider, the longest span having a double web system, which was about the last of the type, as after 1885 they began

to disappear. It had a height of 40 feet above the water, and was reconstructed in 1905. The Sioux City high level railroad bridge over the Missouri (1888) with four spans of about 400 feet had parallel chords and an under clearance of 50 feet. Henderson bridge (Fig. 89) over the Ohio for the Louisville and Nashville Railroad, has a 525-foot channel span and eighteen smaller ones connecting with two and one-half miles of timber trestle. The Cairo bridge of the Illinois Central Railroad over

Fig. 89.

the Ohio river (1889) is 10,560 feet long, including the twelve spans and viaduct, and was then the longest bridge in America.

Since 1888 other simple span railroad bridges have been erected over the Ohio at Cincinnati, Ceredo, Brunot's Island, Louisville, Benwood, and Point Pleasant. The Cincinnati bridge of 1888 has one 550-foot and two 490-foot river spans with double railroad, highway and footwalks, a total width of 67 feet with 1,500 feet of approach on the Covington end, and 2,300 feet on the Cincinnati end. It is the design

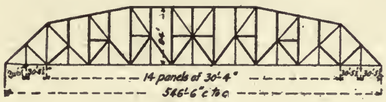


Fig. 90.

of William H. Burr, and contains 10,180 tons of steel. The Ceredo railroad bridge, with four spans of 304 feet and one of 521 feet, is notable chiefly for the use of double bottom chords. It is 34 feet wide between truss centers but carries only one track, being designed by Messrs. Doane and Thomson. The Brunot's Island bridge, a few miles below Pittsburg, with twenty-nine spans, has one of 416 feet and another of 525 feet. The one at Louisville (Fig. 90), of 1893, with

three spans of 550 feet, was designed and built by the Phoenix Bridge Company, and during erection two of the large spans weighing 1,000 tons each, collapsed, killing eleven people. Its total length is 9,360 feet, including 4,075 feet of approach on the Indiana side, and 2,740 feet in Kentucky. The Point Pleasant bridge, first built 1882-84, was renewed in 1909 with five main spans, one of 415 feet with a clearance under it of 90 feet.

251. The most important truss bridge of the time in Great Britain was that over the **Tay at Dundee,** Scotland, completed in 1877 after six years in construction. It carried two

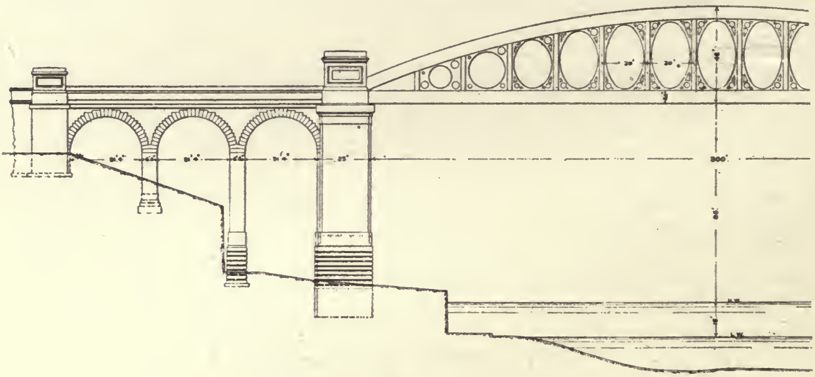


Fig. 91.

lines of railroad on eighty-five wrought iron spans with a total length of 10,350 feet. Some of the piers were brick, but most of them were cast iron cylinders with wrought iron struts and braces, and the clear headroom beneath it is 85 feet. It was designed by Sir Thomas Bouch, and completed after much delay caused by two different contracting firms engaged in succession on the work. After only two years' service, twelve spans were blown down with a train of passenger cars, and about one hundred persons drowned. Construction was again started by William Arrol and Company

of Glasgow from plans by W. H. Barlow, and was completed in 1887. The new bridge contains 18,000 tons of steel, and of the eighty-five piers, seventy-three are composed of double cylinders. The Wear river bridge at Sunderland (Fig. 91), with wrought iron girders 310 feet long and 42 feet deep, designed in 1879 by T. E. Harrison, has a plate web without diagonals, and large curved web openings in each panel. It adjoins Burdon and Stephenson's cast iron arch. The bridge, over the Dnieper at Jekaterinoslaid (1884), with fifteen spans, is one of the longest in Europe. Two bridges in India and Australia, finished in 1888 and 1889, over the Ganges and Hawkesbury rivers, possess more than usual interest. The Ganges bridge at Benares, India, crosses the river where it is 1,600 feet wide and 30 feet deep, and like other rivers in Northern India, the water sometimes rises 40 to 50 feet, with a current of 12 to 15 miles per hour. Seven spans are 356 feet between pier centers, and the remaining nine spans 114 feet. The lattice girders with parallel chords are 35 feet deep, and 22 feet apart for single track, and piers are a combination of brick and concrete. The bridge is 3,568 feet long, and piers go down 141 feet below low water. It was under the direction of F. T. C. Walton, and construction occupied five and one-half years. The Hawkesbury bridge, crossing a river of the same name, seven miles from the sea, was one of the first which was opened for world-wide competition, fourteen designs being submitted by American and European firms. It contains seven spans of about 416 feet, with trusses 28 feet apart for double track. The floor is 42 feet above water which is 40 feet deep, and the foundation bottoms are 227 feet below the rails. Each span weighs 800 tons and was floated into position on pontoons, and lowered on the piers. The foundations were very expensive, and the whole structure cost upwards of $1,600,000.

252. In 1888 statistics showed that, for ten years or more, truss bridges on American railroads had been failing at the rate of twenty-five per year, which averaged one bridge per year for every 5,000 miles of railroad. In 1890 the length of iron and steel bridges on American railroads, estimated as single track or equivalent, was two and one-half lineal miles with spans exceeding 500 feet, four lineal miles with spans of 500 to 400 feet, and five lineal miles with spans of 400 to 300 feet, or a total of eleven and one-half miles with spans exceeding 300 feet. Many of these old bridges were strengthened from time to time, to carry the greater loads of interurban cars or locomotives.*

253. Structural steel, with a safe working strength 20 per cent greater than wrought iron, came into general use about 1890, and in less than five years it was exclusively used for bridges, and wrought iron shapes were no longer rolled. The years 1894-95 are, therefore, the beginning of the steel period.

254. Several large bridges over the Missouri were built or projected after 1890, including those at Kansas City, Bellefontaine, Nebraska City, and Omaha. The one at Kansas City, known as the Winner bridge, with four spans of 423 feet, was commenced in 1890, and the piers and a mile of timber trestle were completed, but work was then abandoned and for twenty years the piers, standing seventy-five feet above the water, have awaited the erection of the superstructure. The Nebraska City and Bellefontaine bridges, both designed by George S. Morrison, and completed in 1895, have channel spans exceeding 400 feet in length. The trusses in both cases have parallel chords, and the one at Nebraska City is probably the last of the double system Whipple type. Trusses are 22 feet apart for single track and the deck which

*Strengthening Traction Bridges. H.G.Tyrrell in Street Railway Review, April 15, 1905.

is 53 feet above high water, is floored over for carriage travel. The Bellefontaine bridge (Fig. 92) has single system trusses, with subdivided panels, and sub-ties to the upper panel points. The Merchants' bridge over the Mississippi river at St. Louis, completed in 1890 under the direction of George S. Morrison and E. L. Corthel, contains three spans of 517½ feet, with trusses 30 feet apart and 75 feet deep for double track. On the east side of the river are three additional spans of 125 feet. Another over the same river at Hastings, Minn., (1895) has a 375-foot span, 55 feet above the water, and contains an unusual feature in the way of a spiral approach at one end. The combined railroad and highway bridge over the Missouri at Sioux

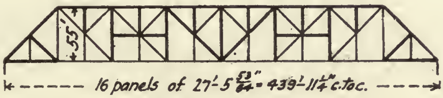


Fig. 92.

City, Iowa, (1896) has two central fixed spans of 490 feet, with a 450-draw at each end.

255. The **longest highway bridge** in America was completed in 1893 across the bay at **Galveston,** Texas, with eighty-nine bowstring spans of 80 feet, and a draw, all supported on concrete piers. The metal work was 7432 feet long, and the pile trestle approach 3,877 feet, making a total length of 11,310 feet. The superstructure cost $13 per lineal foot, or $1,040 per span, and the cedar pile approach cost $6 per foot, the whole bridge costing $192,000. Piers stood on piles and the spans were floated into position on barges. It was destroyed September, 1900, in the hurricane which devastated the city and district. An important bridge (Fig. 93) containing the **longest highway draw span** in existence, was erected across the Connecticut river at Middletown (1896).

Previous to building it, communication between the towns of Middletown and Portland had been mantained by ferries. The site selected was 850 feet upstream from the old railroad bridge, and 300 feet below the end of Willow Island. It is 1,300 feet long, has a 26-foot roadway, and provision for two sidewalks on brackets. Besides the 450-foot draw span, it contains two spans of 200 feet, and two of 225 feet. The draw is operated by electric power from two sources, and opens

Fig. 93.

against wind pressure in thirty seconds, the whole bridge*, including substructure and superstructure, costing $180,000. The superstructure and all machinery were designed by the writer. The Sixth Street bridge at Pittsburg (1897) (Fig. 94), with two spans of 440 and 445 feet, has lenticular trusses 44

*For full description and credits, see London Engineering, March 1, 1901, and Railroad and Engineering Review, June 8, 1901.

*"Reports both false and malicious, concerning the design of this bridge, were published through the medium of various journals of September, 1901, and February, 1902, by those who desired personal aggrandisement. The writer of one of these reports is now confined in an asylum, and another is no longer connected with the construction of bridges or civil engineering.—M. K. T."

feet apart, with 10-foot projecting walks outside. The lower chords are inverted, stiffened three-hinged arches, the center line of tension lying midway between the stiffening cables.

256. The Delaware river bridge at Bridesburg (1896) has three spans of 537 feet, and 330-foot draw for double track, each of the long spans weighing 2,090 tons, while the draw weighs 930 tons. The steel traveler used in erection was 110 feet high, 81 feet wide at the top, and 46 feet wide at the bottom, weighing 146 tons. Two important bridges appeared in Canada in 1897-98 at Montreal and Cornwall, the first being the rebuilding of Stephenson's old tubular bridge over the

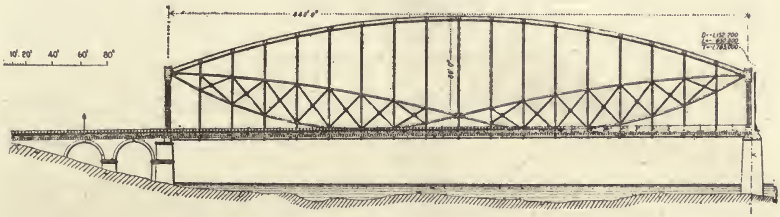


Fig. 94.

St. Lawrence river after fifty years of continuous service. The old piers were in excellent condition, and only required extending on the down stream end. The new bridge has twenty-four spans of 254 feet, and one of 348 feet, with two lines of trusses 31 feet 2 inches apart on centers. Between the trusses are two lines of railway, intended for both steam and electric cars on the same rails. On outside brackets are two 10-foot roadways, and two footwalks 6 feet wide, making the total width of platform 65 feet. The whole bridge contains 20,000 tons of steel. The other structure over the St. Lawrence, at Cornwall, was designed and built by the Phoenix Bridge Company, with three spans of 370 feet, and curved top chords, but during erection two spans fell, killing seven people, the accident being similar to that which happened to

the two spans of the Louisville bridge built by the same company, when eleven workmen were killed. The St. Francis river bridge (Fig. 95), at Richmond, Quebec, with two spans of 371 feet, has the longest riveted simple truss highway span in America. Trusses are double intersection Warren, with parallel chords, 40 feet deep, and panel lengths of 20 feet.

257. Structural work for bridges began to be extensively exported to foreign countries about 1898, and since that time many of the longest ones in China, Japan, Africa, South America, and other countries that are without structural shops of their own, were sent from America. One of the first was a railroad bridge with ten spans of 200 feet for Korea (1899), and another was the **Athbara bridge** in Egypt, with seven

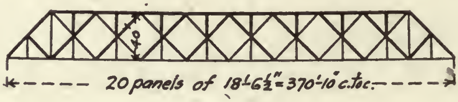


Fig. 95.

spans of 150 feet, containing 800 tons of steel. The last was of no especial interest in itself, but was largely advertised because of the short time occupied in its manufacture and erection. The fabrication was completed in thirty-two days and the material shipped from America in forty-two days after commencing work, and the erection completed in forty-eight days more. Each span was erected in succession by anchoring back to the previous one, and cantilevering the parts out to the next pier. It was originally designed for a live load of only 2,000 pounds per lineal foot, and the trusses are now (1910) being renewed, though the old floor system was sufficient. The work is being done by an English company, and completion is required within six months. The Godavari river bridge on the East Coast Railway at Rajahmundry, India, completed in 1902, contains fifty spans of 150 feet, with total length of 9,100 feet. The Amou-Daris river bridge in Russia, with twenty-five

spans of 210 feet on stone piers, is the longest in that country and replaced a wooden trestle. It carries a line of railroad and was opened in July, 1901, the steel work being made by Russian firms. Another on the Trans-Siberian railroad over the Yenesei river is 2,975 feet long, and contains a span of 469 feet.

258. Three long span highway bridges cross the Great Miami at Hamilton, New Baltimore and Elizabethtown, Ohio. The Columbia bridge (Fig. 96) at Hamilton (1899), with one

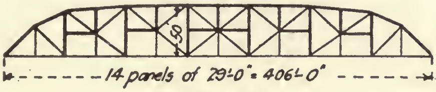


Fig. 96.

span of 406 feet, has trusses 22 feet apart with cantilever walks carrying an asphalt road and concrete sidewalks. Trusses are 50 feet deep, and the whole weight of steel, including buckle plates, is 650 tons. The truss depth is unfortunately insufficient for the heavy floor, and the excessive vibration under moving loads gives a feeling of insecurity. The New Baltimore bridge (Fig. 97) over the same river (1901) with a span of 465 feet, has deeper trusses and a more pleasing outline,

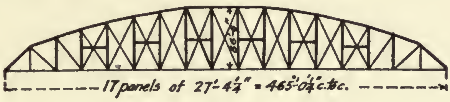


Fig. 97.

but the panels are too short for economy or proper appearance. Trusses are 25 feet apart on centers, with wood floor system proportioned for a six-ton load without cars.

259. A consolidation of twenty-four competing bridge companies, with a capital of $70,000,000, was formed in 1900, under the name of **The American Bridge Company,** a name which had been adopted by Rust and Boomer of Chicago in 1851, and the new company, with branch offices in many

American cities, constructed many of the largest bridges. The Davenport bridge over the Mississippi river (1900) contains seven fixed spans, the longest being 365 feet, and a 442-foot draw, with 850 feet of viaduct in spans of 30 to 70 feet, the total length being 3,157 feet. Another over the same river at Dubuque (1902) has two channel spans of 380 feet. Other long span bridges are at Clarion (1904) (Fig. 98), for the Pittsburg and Lake Erie Railroad, with 31-foot panels and a

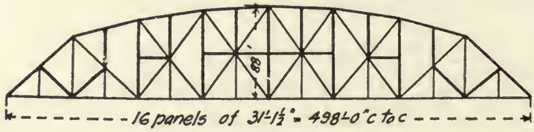


Fig. 98.

span of 498 feet, the Benwood bridge (1904) over the Ohio with stiff bottom chords for cantilever erection, the Plattsmouth bridge (1904), the South Tenth Street bridge, Pittsburg (1904), the Mobridge high level railroad bridge over the Missouri (1907), with three spans of 410 feet, and the Columbia river bridge at Vancouver, Washington (1909). The Vancouver bridge has forty-eight concrete piers, ten of which are in the river and thirty-eight on the island. The camel back

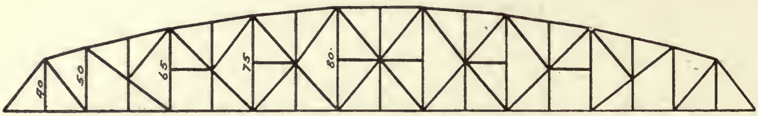


Fig. 99.

trusses are 30 feet apart for double track, and over the channel is a 464-foot draw, the whole bridge costing about $1,000,000. The Donora bridge over the Monongahela (1910) for highway and electric railway travel has five spans, the longest being 515 feet.

260. The length of all previous simple truss spans was sur-

passed in 1906 by the Elizabethtown bridge over the Great Miami river (Fig. 99)), which has a single **span of 586 feet** between end pins. The trusses are 80 feet deep, with points of the upper chord on a parabola, and they are placed 32½ feet apart on centers. The main panels are 65 feet long, divided by sub-panels at the center, making square ones for the lateral system. It was built from designs by the writer, and because of its great length many alternate plans were prepared before the final one was selected.*

The McKinley bridge at St. Louis crosses the river at an elevation of 90 feet above low water with three river spans of 521 feet. Between the trusses are two lines of track for 75-ton electric cars, and at each side are 13-foot projecting roadways, which have a plank floor on wood joists. False work of the center span was washed out in December, 1909, causing a loss of $40,000, but the bridge was opened a year later. The other large bridge under construction at St. Louis, to be known as the Municipal bridge, will have three spans of 668 feet, 110 feet deep with trusses 35 feet apart on centers, and two decks, the upper one being a roadway and the lower one for double lines of railroad. The floor system will be of carbon steel, but the trusses nickel steel. Each span will contain 85 tons of cast iron, 1,800 tons of carbon steel, and 2,695 tons of nickel steel. The contract price for the three river spans was $1,393,000, the same bid being made for construction in either carbon or nickel steel, though the pound price for carbon steel was 3.95 cents per pound, and for nickel steel 5.6 cents per pound. The bids of other companies were $40,000 to $100,000 higher for construction in nickel steel. A. P. Boller, engineer.

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*Elizabethtown Bridge, by H. G. Tyrrell. 1909. Pamphlet, 22 pages. Describing the longest simple truss span in existence. Canadian Engineer, Nov. 5, 1909.

Foreign bridges of unusual proportions completed in the year 1909, are those over the Wear at Sunderland, the Vistula in Prussia, and the Nile at Khartoum. The double deck bridge at Sunderland, for both railroad and highway, is 1,220 feet long between abutments in several spans, 85 feet above the water. The piers are granite, and the whole, including 8,500 tons of steel, cost $2,225,000. The double track bridge over the Vistula, in Western Prussia, was begun in 1905, and completed four lears later. It contains five spans of 256 feet with parallel chords, and five others of 426 feet with curved upper chords. The roadway is 37 feet wide, and accommodates two tracks and a highway. The weight of steel is 13,000 tons, and the cost $2,000,000. Two bridges on the Sedan Railway, in Egypt, are also of unusual length. The first over the White Nile, 192 miles above Khartoum, contains nine spans of 156 feet, and a 245-foot draw, giving two clear passages of 100 feet each. The masonry piers were built on caissons sunk by compressed air. The other bridge, over the Blue Nile, at Khartoum, is supported by twenty steel cylinders 16 feet in diameter. In addition to the approach spans, there are seven of 218 feet. A causeway which is proposed between the Islands of Masnedo and Falster, Denmark, would consist of a series of 275-foot spans and two 150-foot draws, the spans alternating with embankments, and the estimated cost is $2,625,000.

261. **Recent tendency** in construction in England was to use truss depths of about one-eighth of the span, which resulted in heavy chords, accompanied sometimes with excessive vibrations under moving loads. The American practice was to use much deeper and stiffer trusses with correspondingly lighter chords. During the last decade there was a much greater use of solid floors with rock ballast, the greater weight and mass tending to reduce vibrations. Double truss systems

were practically abandoned after 1900, and as the railroads are best able to inspect and observe their bridges under service, it became the custom to have railroad bridges designed by the company's engineers. There was also a great increase in the use of plate girders, and many of the railroads used bridges of standard lengths, for which uniform designs and detail drawings were prepared. This resulted in much saving, for special plans and templets were no longer required. Riveted trusses were generally preferred for span lengths up to 150 to 180 feet, and center lines of truss members were required to intersect at the panel points, thus eliminating internal or eccentric stresses. Stiff bracing was preferred and panel lengths were increased up to a maximum of about 35 feet. Too much curvature of top chords was avoided, as web posts would become light and subject to reversal of stress. Assumed engine loadings increased in many cases up to an equivalent of Cooper's E65 specification. The weight of locomotives and tenders, which in 1860 did not exceed 40, increased in twenty years to 70 tons, and in 1890 to 100 tons. By the year 1900, these weights had still further increased to 125 tons, and in 1910 to 150 tons or more. Bridge pins generally were made much larger than formerly, and trunnion and other bascule forms almost entirely supplanted horizontal revolving spans with their objectionable center piers.

The widest of all highway bridges crosses the Erie canal at Main Street, Lockport, N. Y., the floor being 270 feet across, supported on twenty-seven arch ribs. The widest railroad bridges are at Fifty-first Street, Chicago, 433 feet across, and at the Union Terminal Station in Washington, D. C., over H Street, 790 feet wide, each supporting thirty-three tracks. The Seventh Avenue bridge at New York City is proportioned for heavier loads than any other, while the longest truss in America with riveted joints is the 412-foot span

on the Canadian Pacific Railway, over French river, at Rumford, Ontario. Since 1905 most important bridges have been designed by independent and competent engineers, employed by the purchasers or prospective owners, and construction and fabrication contracts awarded on the plans on a tonnage basis.

On the 190,000 miles of railroad in the United States, there are not less than 80,000 metal bridges, not including wooden trestles, and these have an aggregate length of over 1,400 miles, or one bridge for every three miles of railroad. There are at least thirty-one bridges over the Missouri and forty-eight over the Mississippi below St. Paul. Not less than fifty-five railroad bridges have simple spans exceeding 400 feet in length, and of these at least twenty-five have spans greater than 500 feet. It has further been demonstrated that simple spans are quite practicable in lengths up to 800 feet.

Tyrrell's Formulae for the weight of bridges, trusses, girders, trestles, etc., for railways and highway. See following journals: London Engineering, June 8, 1900; Street Railroad Review, Dec., 1900 and July 15, 1901; Canadian Electrical News, May, 1901; Canadian Engineer, Nov., 1904; Railroad Gazette, Sept. 12, 1902, and Feb. 24, 1905; Engineering-Contracting, Sept. 23, 1908, etc., etc.

CHAPTER XI.

TUBULAR AND PLATE GIRDER BRIDGES.

262. The first wrought iron girder bridge, which had a span of only 31½ feet, was built by A. Thompson in 1841, to carry a highway over the Pollock and Govan railroad near Glasgow, Scotland. It was 25½ feet wide, with six lines of girders. In 1846 William Fairbairn of England erected a pony tubular girder over the Leeds and Liverpool canal with a span of 60 feet, to carry two tracks of the Blackburn and Bolton railway. In the same year a tubular plate girder bridge was built by James Millholland, on the Baltimore and Ohio railroad near Bolton depot, with a span of 50 feet. The sides and bottom of the last bridge were wholly of wrought iron, but the top flange was reinforced with a 12x12 inch timber. The plates used by Mr. Millholland was 38 inches wide and 6 feet deep, the whole bridge weighing 14 tons and costing $2,200. These small spans were the first of their kind, and the beginning of plate girder bridges, which are now so common on American railroads.

263. Experiments made by Mr. Hodgkinson in 1842, to determine the strength of cast iron and wrought iron beams, disclosed the weakness of the former, and it was proposed that cast iron girders should in the future be trussed with wrought iron bars. The first bridge of this kind was at Tottenham, over the river Lea, the work of G. P. Bidder. The uncertainty in reference to the strength of those materials caused George Stephenson, when preparing to bridge the Menai Straits, to

have **extensive experiments** made on the strength of wrought and cast iron. This work he entrusted to three men of known ability, Messrs. William Fairbairn, Eaton Hodgkinson and Edwin Clark, and the completion of their experiments, which occupied more than a year, and cost upwards of $150,000, marked an epoch in the history of bridge building. These experiments showed conclusively the superiority of wrought over cast iron, and after that time cast iron was but little used. In 1847 Mr. Fairbairn secured patents on pony plate girder tubular bridges with upper chords in box form, the cost of which he estimated at $146 per ton.

264. In the next ten years, five large tubular bridges were completed, the Conway, the Britannia, the Brotherton over the Aire, a bridge over the Damietta branch of the Nile, and the St. Lawrence river bridge at Montreal. The **Conway bridge** over the Menai Straits, with a single 400-foot span, designed under the direction of George Stephenson, was opened in 1848. It was at first proposed to span the straits with a single 350-foot cast iron arch with springs 20 feet above the water, but the under clearance was insufficient and the tubular bridge was accepted instead. The portal towers, 90 feet high, were made to resemble the near-by towers of Conway Castle, now in partial ruins. In 1849 Mr. Fairbairn submittd two alternate plans for bridging the Rhine at Cologne with tubular spans, provision being made for both railroad and highway travel. One plan had four fixed pony spans, two of 326 feet and two others of 244 feet, while the other plan proposed two through tubular spans of 570 feet, with double tubes for two lines of railroad and an open 24-foot highway between them. Projecting brackets supported promenades at the sides, and at each end were 200-foot draw spans with a clear opening of 70 feet for boats, approached by a series of land arches.

265. In preparing to bridge the Menai Straits seventeen miles from Conway, Sir Isambard Brunel proposed two cast iron arches of 460-foot span with 230-foot half arches at each end, and he developed a plan for erecting them by placing corresponding voussoirs at each side, held together with rods above the piers. Stephenson had a similar plan, but arches were not favored, because of the decreased headroom towards the springs, and a girder bridge was therefore preferred. The **Britannia bridge,** which is located a few hundred yards from Telford's old suspension of 1826, was designed by Robert Stephenson, and built in the years 1845-50. It carries two tracks of the Chester and Holyhead railway at a height of 108 feet above the water. Each track has a separate tube, the side girders of which are spaced 15 feet apart on centers. The two middle spans are 460 feet each, and the end spans 230 feet, with depths of 30 and 23 feet, respectively. Towers were extended above the tubes to carry suspension chains for reinforcing the girders, should such an expedient be found necessary. The tops of the towers are 196 feet above high water and their total height 230 feet. Each tube is 1,511 feet long, and one tube of the central span weighs 1,600 tons, while each of the 230-foot end tubes weighs 630 tons. The shore spans were built on false work, but the center ones were floated into place on pontoons and lifted with hydraulic jacks. At each end are large figures of reclining lions, and enough attention was given to its architectural treatment to win much commendation. It cost about $3,000,000, and was the first example of a large wrought iron girder bridge. (Fig. 101.)

266. The **Brotherton bridge** over the river Aire, carrying the York and North Midland Railway, on a span of 225 feet, was opened in 1850, the same year as the Britannia bridge. The two tubes for double track were 20 feet deep, but the side girders were only 11 feet apart, and it became necessary to

Fig. 100.

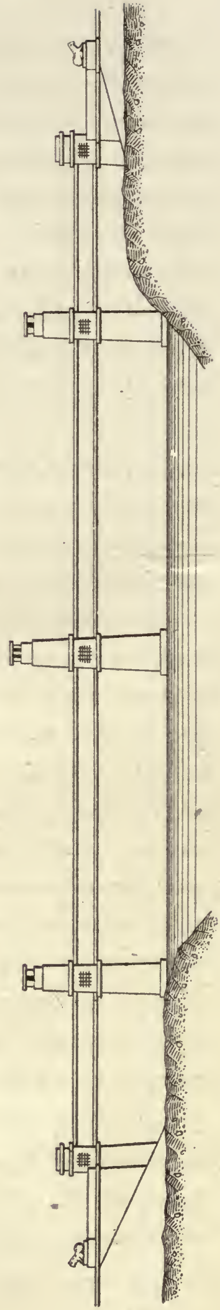


Fig. 101.

cut the tubes down the center and force them apart for greater width. It was Mr. Stephenson's design, but no provision was made for chains like on the Menai bridge. It has since been replaced with a modern truss. The bridge over the Damietta branch of the Nile has the road above the tubes instead of through them.

267. One of the earliest girder bridges in America was on the Pennsylvania Railroad at South Fork, Pa., completed in 1853, and used for forty years; and another, designed by E. S. Philbrick, was used in 1860 on the Boston and Albany railroad. But the largest tubular was the old **Victoria bridge** over the St. Lawrence river, at Montreal. This notable structure was designed by Robert Stephenson and built during the years 1854 to 1860 under his direction with the assistance of James Hodges and A. M. Ross. It was similar to the Britannia over the Menai Straits, the iron tubes being 6,592 feet long, and the total length of bridge 9,144 feet. The piers are 18 feet thick at the water line, and piers and abutments contained more than 100,000 cubic yards of masonry. The bridge carried a single line of railway only and had a cross sectional area of 16x20 feet. The tubes contained 9,044 tons of iron, the clear headroom underneath for the passage of ships being 60 feet, and they were built on scaffolding in their final position, all the shop work of fabrication and punching having been done in England. The floor and roof were of stiffened plates. Ventilation holes were provided in the sides, but as these were insufficient to carry off the gas and smoke from the locomotives, a strip of iron was removed from the roof and the edge of the opening was reinforced with new angles. A permanent traveling carriage on the roof was used for inspection and painting, the area for painting in each coat being 32 acres. The water current in the river is 7 miles per hour, the greatest depth being 22 feet. Peto, Brassey & Betts were contractors,

and the cost is said to have exceeded $5,000,000. Both the Britannia and the old Victoria bridges resulted in serious financial loss to their builders. The latter was replaced in 1897 by a new bridge, which weighs twice at much, and has five times the capacity of the old one, but cost only $1,500,000. A tubular bridge over the English Channel was proposed about 1858 by Mr. Boyd, with 500-foot spans on 190 towers 300 feet high, the estimated cost being $150,000,000. The conclusion, however, after much discussion, was that the best connection between England and France was the open sea.

268. The Penrith bridge on the Great Western Railway, over the Nepean river, New South Wales, 32 miles southeast of Sydney, has three pony or open top tubular girder spans of 186-foot clear opening on piers, 12 feet thick at the top and 198 feet apart. The main girders are 28½ feet apart on centers and the double webs are 13 feet deep, supporting cross girders 3 feet apart, covered with close plank and ballast. The total length of tubes is 594 feet, with an under clearance of 40 feet. Light angle arches on the outer face were added for appearance only. It was designed by Mr. Whitton and completed in 1864. The Gainsborough bridge, carrying the Manchester, Sheffield and Lincolnshire Railway over the Trent river, on two spans of 154 feet, was, in 1865, the largest pony or half-through tubular bridge in England. The girders are 12 feet deep, and 26 feet apart for double track, supported on a center pier and two abutments, each abutment having a 40-foot arch opening. John Fowler, engineer. A double track through plate girder bridge, the length of which has probably been exceeded by only one other, was erected in 1864 on the Eastern Bengal Railway. It crossed the Piallee river with a clear span of 170 feet between abutments. The two side girders with single webs, were 13½ feet deep and 22 feet apart. They were reinforced on the upper flange with cast

iron, and were connected at intervals of 19 feet, with overhead arched braces.

269. The longest simple plate girder spans in America are at Hubbard, Ohio, and Towanda, Pa. The Hubbard bridge carries the Erie railroad over Yankee river on a span of 128 feet 4 inches. The double track bridge over the Susquehanna river at Towanda, on the Lehigh Valley railroad, has thirteen spans of 129½ feet and one span of 120 feet. Another deck bridge over the Beaver river, at Newport, has three spans of 103 feet, with four lines of girders for double track, and another at Bridgeport, Ohio, is 105 feet long, for single track.

270. The longest half-through plate girder bridge is on the West Shore Railroad at Gardner, N. Y., with a span of 119 feet. Another long half-through girder bridge crosses the Mattabessett river at East Berlin, Conn., with a span of 102 feet. The longest four-track girder bridge is on the New York Central Railroad at Lyons, N. Y., with three lines of girders and an opening of 107 feet.

CHAPTER XII.

SUSPENSION BRIDGES.

271. The suspension bridge is one of the earliest types, but it has not been developed or adopted as rapidly as other forms, owing chiefly to its lack of rigidity and the absence of correct theory for proportioning stiffening trusses. It was used in remote ages in China, Japan, India, Tibet, and by the Dyaks of Borneo, the Aztecs of Mexico, and the natives of Peru and other parts of South America. In all early forms the platform was supported directly on the cables, which consisted of twisted vines or straps of hide drawn tightly to remove floor sag, the cable ends being fastened to trees or other permanent objects on shore. Light bridges of this kind, requiring no piers, were economical, and are still common in Peru and in parts of China, India and Ireland. A more primitive bridge consisted of a single rope with a basket suspended from it, which was drawn back and forth by a smaller rope or cord. Single tight ropes were also used with smaller ones at higher levels, to form side support for the traveler. Definite information relating to the early history of bridges in China is lacking, but enough is known to prove that suspensions were used in that country in very remote times. The first one of which the date is given was built A. D. 65 by order of Emperor Ming, in the province of Yunnan, and as described by Kirchen, was 330 feet long, with a plank floor resting on the chains. A similar one at Tchin-Chien was 140 feet long, and another over the river Pei, several hundred feet in length. One in China with the floor resting on the iron suspension chains,

resembling the rope bridges of South America, dates back to remote times, and later records show that all in that country before the sixteenth century had floors supported in this way. Foot bridges of this kind crossing ravines and rivers, permitted the Buddhist to reach his house or temple on the other side.

Turner describes a bridge (Fig. 102) with a span of 150 feet and a mat floor on five chains over the Tehint-Chien river near Chuka Castle, 18 miles from Murichom, East Indies, while more recent ones of this kind may be found at Carrick-a-Rede, Ireland, and one over Taggart Creek in Car-

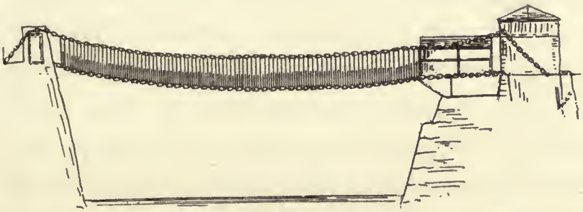


Fig. 102.

ter County, Kentucky, with a span of 140 feet and cables fastened to trees. Iron chains were used for suspensions in Japan 500 years ago or more, at a period when iron was very valuable, and some of these are said to be still in use. Major Remel-describes a suspension bridge in Hindustan over Sampoo with a span of 600 feet, and one of rope over the Kishangauga, Shardi, India, is also mentioned. Humbolt describes several interesting suspension bridges in South America found by him in 1802, one at Quito over the Chambo river having a span of 131 feet. Cables four inches in diameter were supported on timber end frames and fastened to posts driven into the ground, the road lying on the cables and conforming to their curve. Another in Peru is said to have a span of 225 feet. A native bridge at Caucasus with a span of 80 feet and a narrow suspended foot path, strong enough for loaded mules,

had two cables fastened to trees on shore, each cable being made of three twisted creeper vines. The Padus river in Italy was crossed by a suspension bridge, in 1515, built by soldiers for transporting the army and artillery, and a rope suspension to cross the Clain river was used in France at the siege of Poitiers (1595). Iron suspensions were used in Europe as early as 1615 and several are reported in Switzerland in 1650 and in Italy in 1742.

272. The first suspension bridge in England (1741) crossed a chasm 60 feet deep and the river Tees near the High Force, two miles from Middleton. It was 70 feet long, 2 feet wide, and the floor lay directly on the cables, with a railing on each side. It was used chiefly by miners, and fell in 1802, killing one or two people, but was replaced by a similar one known as Wynch bridge, which was standing in 1908. Suspensions were used in America before any other kind of iron bridge, the first scientific ones of the modern type, with horizontal suspended floor, appearing at the beginning of the nineteenth century, though rude ones like that at Caucasus may have preceded them. James Jordan secured an American patent in 1796 on a "suspension bridge," but it was really a bowstring truss with a suspended floor. Those previous to 1810 were chiefly the work of **James Finley,** a native of Fayette county, Pennsylvania, whose first bridge in 1801 over Jacob's Creek on the turnpike between Uniontown and Greensburg, had a span of 70 feet, though he is said to have made experiments with, or models of, smaller ones three or four years before. As the Greensburg bridge was a success, many others were made like it, and the type became the most approved form in the first half of the nineteenth century. The **Greensburg bridge** had two iron chains, one on each side, with links of the proper length to suit the distance between the suspended floor joist. The chains had a sag of 10 feet, or

one-seventh of the span, and passed over masonry towers with the same angle of inclination on each side, being bolted to four large anchor stones on shore. The suspended wood floor was 12½ feet wide without any stiffening trusses, the whole costing when finished about $600. Eight similar ones are said to have been erected the same year, and about forty more prior to 1808, when patents were granted to Mr. Finley on his designs. He made the floors in one solid slab for the sake of lateral stiffness, and used long joists to spread the floor loads over several suspenders. Previous to 1808 he erected one over the Potomac at Washington with a span of 130 feet and a 15-foot roadway supported by two chains of 1¼-inch wrought iron bars; another over Brandywine Creek at Wilmington, Del., with a span of 145 feet and a floor 30 feet wide; two at Brownsville, Pa., with spans of 120 feet; and one at Cumberland, Md., with a span of 130 feet. The one at Wilmington over the Potomac was washed out by a freshet about 1840 and was replaced by a wooden bridge.

273. One of Finley's earliest bridges, 306 feet long, was erected in 1809 over the Schuylkill river at **Fairmount,** Philadelphia, on the site occupied by the Colossus twenty years later. A description says that it was "aided by an intermediate pier," and it is represented in an old illustration with two spans of 153 feet each, being the first appearance of a suspension bridge with more than one span. The cables were made of long iron links from which the floor was hung with rods. It collapsed in 1811 under a drove of crowding cattle, but was replaced by another suspension, which fell January 17, 1816, under a weight of snow and ice. The third bridge opened in June, 1816, had a single span of 408 feet, and a passage way of only 18 inches, and was the work of White and Hazard, who owned and operated a wire mill near by, the cables being made of six ⅜-inch wires. It was notable

for being the first wire suspension bridge in any country, all those in Europe having a later date. The wood floor was without stiffening trusses, and the bridge was safe for only eight persons at one time, and is said to have cost the small sum of $125. A toll of one cent was levied on each passenger. It fell in 1816 under a load of snow and ice soon after its erection, and was replaced by the Colossus, a wooden bridge designed by Wernwag, and opened in December, 1817.

274. One of Mr. Finley's most notable suspension bridges crossed one channel of the **Merrimac river** at Deer Island, three miles above **Newburyport,** Mass. It replaced Timothy Palmer's old wooden one of 1792, and was built under the direction of John Templeton in 1810, with a span of 244 feet between tower centers. The two roads were 15 feet wide, each having two sets of cables containing three chains in each, or a total of twelve chains for both roadways. The links were one inch square and 27 inches long, making a total area of six square inches in each chain, and floor supports were 7 feet apart. The anchorages are 100 feet from the towers and the shore end of cables are not loaded, being supported on timber frames 47 feet wide and 37 feet high above the floor, sheathed over and shingled, and standing on masonry abutments. One chain broke in 1827 under a load of four oxen and a horse, but it was repaired. It was sold to Essex county in 1868 for $30,000, and in the following year the woodwork was wholly rebuilt. It was again strengthened in 1900 by adding two new wire cables to one of the roadways, making the bridge strong enough for a line of electric cars, the work being done without interfering with travel on the other roadway. It has no stiffening trusses, and although the first chain bridge in New England, it still remains. Another suspension bridge with several spans was erected at Newburyport in 1826, and is described later. Mr. Finley designed two bridges crossing the Lehigh

river, one at Northampton, Pa., in 1811, and another at Allentown, in 1815. The Northampton bridge had a total length of 475 feet and three towers supporting two intermediate and two end spans with double roadways and two 6-foot walks, and was the second suspension bridge with more than two towers. The Allentown bridge had two spans of 230 feet, with cables of iron bars carrying a roadway 30 feet wide. It was damaged by fire in 1828 and carried away by a flood soon afterwards. Another old bridge at Island Park, near Easton, Pa., has two spans resting on a pier in the river and a floor following the sag of the cables.

275. Suspension bridges were of two kinds, (1) those with towers on shore and cables loaded only between the towers, and (2) those with towers in the river or valley, and cables loaded over both central and end spans. When preparing designs for a bridge at Runcorn Gap, in 1814, Mr. Telford made experiments and investigations which showed that wire suspension bridges could be built in spans up to 1,000 feet, and while the wire bridge at Philadelphia two years later was the first actually built, Mr. Telford's investigations probably preceded it. The plan for this suspension over the Mersey showed a center span of 1,000 feet with 500-foot spans at each end and 30-foot roadway, the cable sag in the center being only 45 feet. Each of the sixteen cables were to be made of 36 square half-inch bars bound together with wire The water beneath the bridge was 16 feet deep and the plan showed a clear headroom above water of 70 feet, the floor having a sag towards the center of 15 feet. In 1814 Mr. Dumbell, of Warrington, also proposed a bridge from Runcorn, in Chester, across the Mersey to Liverpool.

276. Two foot bridges between different parts of a manufactory were erected at Galashiel over the Galawater (1816) and at King's Meadow, over the Tweed, in the following year.

The first was designed by Richard Lees, with a span of 112 feet and cables of slender wire, at a cost of only $200, while the latter, designed by Redpath and Brown, with a span of 110 feet and 4-foot deck, had similar cables supported on cast iron towers 9 feet high, and with stays, plank floor and rod railing, cost $800. Others of about the same time were the Kelso bridge over the Tweed, with 300-foot span and 18-foot carriageway, and the Thirlstone Castle bridge, 125 feet long with stays. The Dryburg Abbey suspension, over the Tweed, was built by Messrs. Smith, with a 260-foot span and 4-foot deck. It was owned by the Earl of Buchan, and cost 500 pounds sterling. In 1818 it was blown down, but was soon afterwards restored at an additional cost of 220 pounds. Auxiliary stay cables were used and the main ones were 12 feet

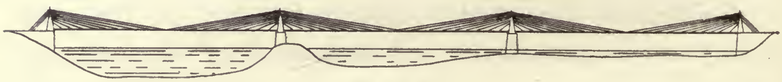


Fig. 103.

apart at the towers, sloping in to 4 feet apart at the span center, this probably being the first use of this arrangement (cradling).

277. Four years after Mr. Telford's investigations for the Runcorn bridge, Mr. James Anderson, a civil engineer of Edinburg, made three designs for chain suspension bridges to cross the **Firth of Forth** (Fig. 103), with three spans of 1,500 to 2,000 feet, and an under clearance for ships of 90 to 110 feet, the estimated cost being $1,000,000. These designs showed two intermediate piers corresponding with those afterwards used for the Forth cantilever. One of the first engineers in England to investigate and develop the suspension bridge was **Sir Samuel Brown,** who in 1811 proposed the use of flat bars or links for cables instead of the square and round bars previously used. During the years 1814 to 1830, although several

of his structures collapsed, Mr. Brown greatly improved the design of suspension bridges, but neither he nor Mr. Telford used stay cables. It was Mr. Brown who, in 1819-20, designed and built the first large suspension in Great Britain, the **Union Bridge,** over the river Tweed, **at Berwick.** It had a span of 449 feet and a road 18 feet wide supported by 12 cables, 6 on each side, with versed sine of 30 feet, passing over piers 17½ feet thick at the road level. The cables hung in three tiers above each other with two chains in each tier, and were of round wrought iron, 2 inches in diameter, and 15 feet long, united by coupling links 1⅛-inch diameter and 7 inches long. The road had wooden floor beams supported by round rods attached alternately to the three cables, loading them equally. Six months after its completion the bridge was blown down by a violent wind storm. In 1823 Sir Samuel Brown designed and built the **Brighton Chain Pier,** 1,136 feet long, with four spans of 255 feet, at a cost of $150,000. The deck was supported by four chains at each side of the roadway with a cable sag of 18 feet in each span, each chain consisting of links 10 feet long joined by double couplings and bolts. The chains passed over four iron towers standing on piles, and at the land end they were carried 54 feet into the cliffs. After being used for thirteen years, the pier was damaged, in November, 1836, by the action of heavy waves during a great storm.

278. Suspension bridges were introduced on the continent of Europe about 1820, one of the first being at Geneva, over the Fosse (1823), with two equal spans of 132½ feet, the work of Colonel Dufour, a French engineer. It had a platform 7½ feet wide and 300 feet long, supported by round rod hangers from four wire cables, two at each side, the upper and the lower cables being 1-inch and 1⅛-inch diameter, respectively. Several other wire suspension bridges were made in France during the same year by Seguin Brothers, of Lyons. The

versed sine or cable sag used by the French engineer, Navier, was one-twelfth to one-fifteenth of the span, while Finley's bridges had a deflection of only one-seventh. Navier was sent by the French Government to England in 1821 to study and investigate suspension bridges, and two years later he published a book on the subject, which was followed in 1824 by a treatise written by the elder Seguin.

279. A project for bridging the **Menai Straits**, between the Island of Anglesea and Carnarvonshire, in Wales, had been considered in England for many years. As early as 1776, Mr. Golbourne proposed high embankments at each side connected by a bridge, and in 1785 Mr. Nichols outlined a plan for a great wooden viaduct. In 1810 Mr. Telford submitted designs for bridging the Straits with a single 500-foot cast iron arch, but the arch design was not favored because of the lessened headroom towards the springs, and a suspension bridge with uniform clearance was accepted instead. Actual construction on the bridge was begun in 1819 under the direction of Thomas Telford as chief engineer, and the following year another suspension was started at Conway, both of which were completed in 1826. The Menai bridge has a central span of 580 feet, and two side spans of 280 feet with four stone arches of 50 feet at one end, and three similar ones at the other end, making a total length of 1,710 feet. It carries a platform 30 feet wide divided into 12-foot driveways with a 4-foot walk between them, at an elevation of 120 feet above low water, the total suspended weight being 643 tons. The sixteen main cables are arranged in four sets vertically above each other, one set at each side of the roadway. The cables have a versed sine of 43 feet and pass over stone towers founded on rock, the top of towers being 152 feet above high water and the thickness at the road level 29 feet. Each chain contains five iron bars 3¼ by 1 inch, 10 feet long, united by

8x16-inch links and 3-inch pins, and they are secured in anchor pits reached through tunnels. The total cross sectional area of the main chains is 260 square inches and the bridge with approaches cost 120,000 pounds sterling, and is still in use. After the designs were completed and a contract for the construction awarded, Mr. Telford increased the amount of material over that shown on the original plans, and made the towers higher, the extra quantities being paid for at agreed unit prices. It is situated only a few hundred yards from the Britannia tubular bridge, and when built was the first great suspension. It was seriously injured by a wind storm in January, 1839, when one-third of the hanger rods were broken and both roadways made impassable, but it was soon afterwards repaired. It crosses the channel at the narrowest point, over water 40 feet deep. (Fig. 105.)

280. The **Conway bridge,** across a deep and rapid channel in North Wales, adjoins the old Conway Castle, now in partial ruins, and was completed in 1826 after six years' work. It was designed by Thomas Telford and the stone work was made to harmonize with the round towers and battlements of the castle. It has a span between towers of 327 feet and has four eye bar chains on each side 3½x1 inches by 9 feet long, vertically above each other but not connected. The chains have a center sag of about 22 feet and are anchored back into the solid rock. The bridge continued in use in its original condition for more than eighty years, but was then found insufficient for modern loads and travel, and was strengthened in 1904 by the addition of new anchorages, four new wire cables, two on each side, new suspension links and stiffening girders 8½ feet deep. A new 6-foot walk was also added on the North side, the cost of reinforcing being $32,500.

281. In 1826-27, when Mr. Telford was completing the two suspension bridges at Bangor and Conway, a notable one of

Fig. 104.

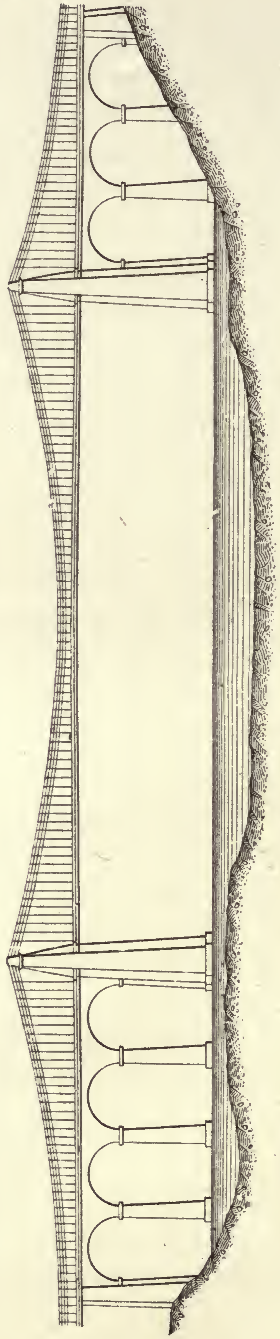


Fig. 105.

several spans was started under the direction of Thomas Haven, at **Newburyport, Mass.** (Fig. 104), crossing the Merrimac river betwen Newburyport and Salisbury, below Carr Island. It had three river and two shore spans supported on four piers and two abutments. At the Newburyport end was a small double leaf bascule draw span separate from the rest of the bridge, but as the main river was about 1,000 feet wide,

Fig. 106.

the spans must have been 150 to 200 feet in length. The cables were wrought iron links with four groups of three in each, supported on timber towers 31 feet high standing on log cribs filled with stone.

282. The old **Hammersmith bridge** (Fig. 106), over the Thames at London, was designed by William Tierney Clark, and erected in 1824-27, with a central span of 400 feet and

Fig. 107.

two side spans of 147 feet. It was found in 1887 to be too light, and was rebuilt on the old foundations under the direction of Sir J. Bazalgette at a cost of 82,100 pounds. It is ornamental and one of the most attractive objects in London.

283. The first use of steel for bridge building in any country was for the chain bridge at Vienna, over the Danube canal (1828), with a span of 334 feet, the work of engineer Von Mites. The cables were flat eye bars of open hearth steel. It was taken down in 1860 and another suspension (Fig. 107),

designed by Schnirch, with a clear span of 255 feet, placed on the site, the latter being remarkable for being the first and only railroad suspension bridge in Europe, but in 1884-85 the second one, which had two lines of braced chains at each side, 4 feet apart vertically, was replaced by an iron arch.

284. Two suspension bridges appeared in England (1829-30) from the plans of Sir Samuel Brown, the first one at Montrose having a span of 432 feet, and cables of flat wrought iron bars. Nine years after it was opened it met the fate of Mr. Brown's other bridges at Berwick and Brighton. It partly collapsed in 1830 under a crowd of people viewing a boat race, causing great loss of life, and was blown down and destroyed in 1838. It was afterwards reconstructed by Rendel and stiffened with trussing. Mr. Brown's bridge over the Tees (1830), carrying a railroad from the Durham coal fields into Yorkshire, had stone towers and a clear span of 281 feet, with a cable sag of 28 feet, the floor being 20 feet above high water. The side trusses were entirely too light for engine loads, and after being in use for some time, the deflection was so great that piles were driven under the platform to support it, and in 1841 nothing remained except the chains. It was replaced in 1842 under the direction of George Stephenson by a cast iron girder bridge of five spans for double track, the three river openings having clear lengths of 89 feet each. It remained until replaced in 1906 with steel. A bridge at Broughton, near Manchester, failed in 1831 under the march of sixty soldiers, and a similar accident happened at Angiers, in France. A chain bridge over the Regnitz, at Bamberg (1829), with a span of 210 feet, replaced an old timber arch of 1808, and in 1889 the suspension was in turn replaced by a cantilever. In building suspension bridges, cables were at first made on land and then transferred to the towers, but in 1831 M. Vicat, when building a bridge over the Rhone, wove the cable in place,

and the same method was used for the Tours and Roche-Bernard suspensions in 1840.

285. In 1832 a proposition was made to the United States Congress by Charles Ellet, a young man only twenty-two years of age, to cross the Potomac river at Washington with a wire suspension bridge of 1,000-foot span. His proposal was not accepted, but fifteen years later Mr. Ellet was recognized as one of the leading bridge engineers of America, and built a suspension at Wheeling with a span exceeding the one which he proposed at Washington.

286. Two important bridges were erected in 1832 and 1834 at **Fribourg**, Switzerland, and until the end of the nineteenth century, the larger one remained the longest span of

Fig. 108.

any kind in Europe. The smaller bridge crossed the Saone Valley with a span of 195.5 feet, the cables being anchored into rock banks, while the larger one, designed by M. Chaley, had a single span of 870 feet between tower centers, versed sine of 63 feet, and carried a floor 810 feet long at an elevation of 167 feet above the Sarine Valley. (Fig. 108.) It originally had four iron wire cables, two on each side of the roadway, each cable containing 1,056 wires, and the platform which was two feet higher at the center than at the ends, had a 15-foot roadway and two 3-foot sidewalks, with wood floor beams hung from the cables with 1-inch wire suspenders, making a total width of 21 feet. The piers are solid masonry 20 feet thick at the road level, and rise 66 feet above it with Doric porticos. The cables are securely anchored in the rock, the

anchor chambers being reached through tunnels. It was severely tested by a detachment of 15 cannon, 50 horses and 300 people passing over it, the deflection under the combined load being 39 inches. The original cost of the bridge was 24,000 pounds sterling, but in 1880 it was reinforced at considerable expense by adding one more cable on each side. M. Chaley also erected suspension bridges at Beaumont, over

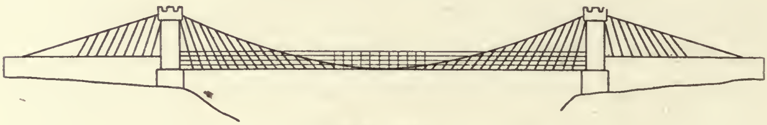


Fig. 109.

the Sarthe, at Charite, over the Loire, Cormery, over the Indre, at Percey, in the Jura Mountains, and at Paris.

287. **Mr. James Dredge** evolved a new suspension bridge principle (Fig. 109) in 1832, with floor rods inclined instead of vertical, and chains hanging in vertical planes increasing uniformly in sectional area from the span center to the towers, combined with a compression member at the floor level. He

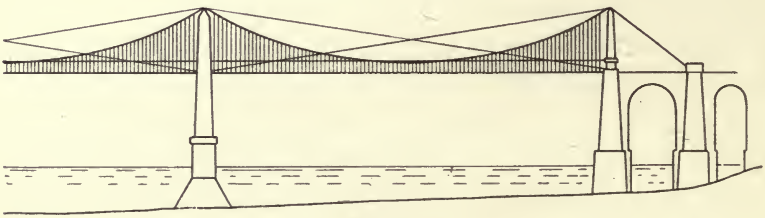


Fig. 110.

designed a bridge on this principle at Balloch Ferry, Loch Lomond, with a total of 292 feet and 200 feet between towers, which were 20 feet apart transversely. Each cable had thirteen rods at the tower of ⅞-inch diameter, decreasing to a single rod at the center of the span. Cables were loaded on both sides of the tower, and as the two sides balanced each other,

the bridge was more cantilever than suspension. Mr. Dredge designed a similar one with latticed side trusses and battlemented towers to cross the river Spey.

288. The **Dordogne river** bridge at **Cubzac** (1839) with five equal spans of 357 feet (Fig. 110), supported on cast iron towers, had a system of bracing between the towers above the floor, and the cables at the ends slope down at an angle of about 45 degrees to the masonry abutments, which are pierced with transverse arches. The towers are 82 feet high, their tops being 126 feet above water.

289. The Weser suspension bridge, near Hameln, by Wendelstadt (1839), was the first use of triangular bracing between double chain cables. It was removed in 1899 to Hessich, Oldendorf, and the Weser bridge rebuilt as a cantilever.

Fig. 111.

290. In 1840 the elder Seguin erected a railroad suspension over the Saone with two spans of 137½ feet each, and three cables at each side with a sag of 16 feet 8 inches, stiffened with girders about 8 feet deep. It was not a success, for after four years it was replaced by a stone bridge.

291. The Neckar suspension at Mannheim, by Wendelstadt (1845), was replaced in 1890 by a cantilever with curved upper chord resembling a suspension. A chain bridge over the Ruhr at Muhlheim, Prussia (1850), by Malberg, also had iron towers.

292. A wire suspension bridge at **Roche-Bernard,** France (Fig. 111), over the Velaine, had a span of 650 feet, 110 feet above the water, with four wire cables having a sag of 50 feet.

It was completed from designs by Le Blanc, but was wrecked by a gale in October, 1852, and counter cables were added in its restoration. The end cables are not loaded and have the same angle of inclination at each side of the towers, being made continuous around the anchorages in the end vaults, similar to the Lorient bridge. Each approach was supported on a series of three masonry arches of 31-foot span. Other wire suspensions prior to 1842 were those of Lorient and Suresne, France, the former having a span of 600 feet. The Suresne bridge over the Seine (Flachat and Petiet, Engineers) has a center span of 203 feet, with a one-tenth cable sag, and two side spans of 139 feet each. It has ornamental stone towers and carries a roadway 22 feet wide and 500 feet long at a height of 35 feet above the water. The Suresne bridge, Paris, has cables of thin flat iron, which is stiffer though not as strong as wire. A double chain bridge over the Moldau, at Prague (1842), designed by Schnirch, has center and side spans of 433 and 109 feet, respectively, with stone towers. The Douro river suspension bridge at Oporto (1842), with a span of 558 feet, has eight cables, four on each side of the road, with a sag of 45 feet, anchored at one end into the cliff and into horizontal foundations at the other end. The stone towers are 59 feet high and the road 20 feet wide, the construction being under the direction of M. Stanislan Bigot, and costing $100,000. A bridge at Seraing, Belgium, over the Maas (1843), with a center span of 344 feet, was one of the first suspension bridges with cast iron towers, others being the Dordogne at Cubzac (1839) and the Ruhr at Muhlheim (1850). The Gotteron bridge (1840) with a span of 640 feet at a great height, had the ends at different elevations.

293. Ten years after proposing the span of 1,000 feet at Washington, Charles Ellet designed and built a wire bridge across the Schuylkill river at Fairmount, Philadelphia (1842),

to replace the Colossus, burned in 1838. From 1809 to 1816, previous to building the Colossus, the site had been occupied consecutively by two other suspension bridges, both of which collapsed under excessive loads. Mr. Ellet's suspension had a span of 358 feet, and was supported by wire cables, five at each side. It had a clear width of 25 feet, and remained in use until 1874, when it was replaced by the present double deck truss bridge.

294. Two important bridges at Pittsburg (1844-47) were the work of Mr. John A. Roebling, one of them being the **suspension aqueduct** over the Allegheny river and the other the Smithfield Street bridge over the Monongahela, replacing an old wooden one burned in 1845.. The aqueduct had seven spans of 162 feet with two 7-inch wire cables, supporting a wood water flume. The project met with opposition and was reported impracticable by other engineers, but was completed by Mr. Roebling in 1845 and remained in use until the canal was abandoned in 1861, when the bridge was removed. Mr. Roebling was the first to use suspension aqueducts, and previous to 1848 he built four others with openings of 115 to 170 feet. The **Smithfield Street suspension bridge** over the Monongahela, stood on piers of an old wooden one which had eight spans of 188 feet. It had two cables, 4.5 inches diameter, and cast iron towers which were truncated pyramids, 7½ feet square at the base and 16 feet high, standing on stone piers. The road was 20 feet wide and had two lines of car track, the total width of bridge being 35 feet. It was completed by Mr. Roebling in 1847 and continued in service for 35 years, carrying the heaviest kind of street traffic, electric cars, steam rollers and eight-horse teams drawing heavy trucks loaded with iron and machinery. A system of wire stay cables was used, but the loaded span sometimes deflected as much as 2 feet, with a corresponding rise of the adjoining unloaded

spans. It was taken down in 1882, and a contract entered into for building a new suspension on the site with two river spans of 360 feet and end ones of half this length. But a change of management in the construction company caused the contract to be nullified, and the present two-span lenticular one was erected on the piers intended for the new suspension.

295. The older of the two chain bridges over the **Danube at Budapest** was the work of W. Tierney Clark in the years 1839-49. This has a distance between tower centers of 666 feet, with a cable sag of 47 feet, and two side spans of 298 feet, with total waterway of 1,250 feet. The stone towers rise to a height of 200 feet above the foundations and are very artistic both in general outline and detail. It has four flat eyebar cables and an outside width of 46 feet. It was very severely tested when, for two days, the Hungarian army retreated across the bridge, followed by 30,000 Austrians, both armies having cannon, heavy ammunition and supply wagons. W. T. Clark died before the bridge was completed, but it was finished by his brother, Adam Clark.

A design made in 1850 by Schwedler for a stiffened suspension at Cologne, which received the first prize, had 620 foot spans and double center towers 138 feet apart, with a double bascule draw between, and an elevated platform for pedestrians 72 feet above the main deck similar to the later Tower Bridge at London. The cables were stiffened by a series of members from the towers.

296. The Hungerford foot bridge over the Thames, at Charing Cross (1842-45), was the work of Isambard K. Brunel, and was the longest chain suspension, having spans of 676 feet, versed sine of 50 feet, and two side spans of 329 feet. The four main chains, two on each side, were composed of 7x1 inch flat links, 24 feet long, connected with 4⅝-inch pins. The road was 14 feet wide and the wooden beams were sus-

pended from the chains with rods hung from small metal levers, the two ends of which were supported separately from each chain, to load both cables uniformly. Each chain was connected to the saddles which rested on iron rollers over brick towers, allowing a movement of 18 inches in either direction from the center line. It was removed to make room for the new Charing Cross railroad bridge, but was re-erected at Clifton, England, in 1863. To provide for expansion Mr. Brunel used pendulums or suspenders on one of his bridges, at the top of towers, for supporting the cables, and a similar arrangement was afterwards used for a bridge over the Allegheny near Pittsburg. Mr. Brunel sometimes used inverted or up-curving cables under the floor to stiffen it against upward wind pressure, and the inverted cables on two bridges of this form built by him on the Isle of Bourbon, had one-third the capacity of the main cables.

297. It is well known that in designing the Britannia tubular bridge provision was made for supporting the tubes at the center with chains, and the towers were extended to the proper height with openings for the cables, should they be required. Mr. Stephenson investigated several suspension bridge forms, including one in which the horizontal deck was carried above the chains instead of below them. He proposed wrapping the cables around the anchor masonry and reported the plan suitable for spans up to 150 feet in length. He also investigated a combination or double suspension system for the Britannia, with cables supported on alternate towers. Mr. Stephenson reported that the 300-foot suspension at Stockton had excessive deflection and "a wave 2 feet high rose up in front of the engine." His conclusion was, therefore, that suspension bridges were unsuitable for railroad purposes, excepting for exceedingly long end heavy spans, a conclusion which is confirmed by recent investigation and experience.

298. The wire bridge over the **Ohio river at Wheeling,** (1846-49) with a central opening, 1,010 feet, was the longest span of any kind in existence. It was the work of Col. Ellet, and was somewhat similar to one which he proposed 14 years before for the Potomac river at Washington. The Wheeling bridge was 24 feet wide, the platform being 97 feet above low water. On each side of the road were six separate cables side by side, containing a total of 6,600 wires. It was damaged by a tornado in 1854, when the floor was turned over and all but two of the cables were broken in succession at the anchorage, though one cable of 150 wires broke at the span center. It was repaired the same year by Roebling, the separate strands on each side being united into solid cables and placed farther apart at the towers than at the center, which greatly assisted in making the bridge rigid against wind pressure. It was again rebuilt in 1862. The failure and repairing of this bridge brought the **systems used by Ellet and Roebling** into sharp contrast. Mr. Ellet used wires in separate strands side by side, with iron bars fastened across them from which the suspenders hung, while Mr. Roebling used wire cables in cylindrical form enclosed and wrapped with light wire to protect them from the weather. In his system, the suspenders hung from clamps surrounding the cables, which were generally in planes sloping at an angle from the vertical, with systems of auxiliary stay cables radiating from the towers to successive panel points of the floor system. The stays added stiffness to the floor and relieved the main cables of much load, but the distribution of load on the main and auxiliary cables was uncertain and their use was afterwards abandoned.

299. While the Wheeling bridge was being considered, Mr. William Merritt of St. Catharines, Ontario, proposed in 1844, the construction of a suspension bridge across Niagara gorge, and through his efforts the first charter was obtained

in 1846. Four prominent bridge engineers, Charles Ellet, John Roebling, Samuel Keefer and Edward Serrell, were invited to report on the feasibility and cost of such a work, and their reports were all favorable. It is interesting to note that each of these men in later years actually built a bridge across the Niagara gorge. In 1847, a contract was given to Mr. Ellet at $190,000 to erect a bridge with a span of 800 feet and two 7½-foot roads, two 4-foot sidewalks and a railroad track in the center, but preliminary to starting work on the larger bridge, which was not completed according to his plan, Mr. Ellet made a smaller foot bridge, 7½ feet wide, over the gorge, at a cost of $30,000, which was strengthened the same year to carry material and supplies for use in the larger one. It had an opening of 770 feet and a kite was used to take the first cord across, the light string drawing over a larger one, which in turn pulled over a rope to which was attached the first wire cable. Mr. Ellet was so proud of his achievement when it was nearly completed that he mounted his horse and rode triumphantly across the narrow unguarded platform on horseback, at a height of 250 feet above the river, before the side railings had been placed. The bridge remained in use until the heavier one was finished in 1854, when the light one was no longer needed and was removed. In March, 1848, Mr. Ellet erected a **basket ferry over the Niagara** river about two miles below the falls, on which a toll of $1.00 per passenger was charged. The car or basket was made of light iron work with seats on each side and was large enough for four persons. It hung by a trolley from a single wire cable and was drawn back and forth between the opposite banks.

300. Mr. Ellet made a report and plan in 1849 for a proposed railroad suspension bridge to cross the Connecticut river at Middletown, Conn., with a single span of 1,050 feet, at an elevation of 140 feet above the water. The railroad

company was considering alternate plans for a low level bridge with a draw span, and a fixed high level bridge, but the low one with draw being the cheaper, was accepted and built. In 1896 it was found too light for the increased train and engine loads and an examination and report was made by the writer for strengthening it. (Railroad Gazette, August 2, 1901.)

301. The failure of Samuel Brown's suspension bridges at Berwick, Brighton, Montrose and Durham, was a serious check to the building of these bridges in England, and in 1850 a wire bridge at Angiers, France, collapsed under a company of marching soldiers, the wires having corroded at the anchorage. In the following year construction was started on the Nicholas suspension bridge in Russia, crossing the Dnieper river at Kieff, with four intermediate spans of 440 feet and two end ones of 225 feet. The road is suspended from four chains composed of eight rows of flat bars 11x1 inch, 12 feet long, supported on fine stone towers. It was completed in 1853 and is still in use.

302. The next bridge over the Niagara gorge was started in 1850 at Lewiston, two miles below the falls, under the direction of Captain Edward W. Serrell. The distance between cable supports was 1,040 feet, the road was 850 feet long and 21 feet wide, and the cable sag 87 feet. In 1861, when the guy cables had been temporarily removed, the bridge was wrecked by a wind storm and it was not repaired or rebuilt until 1899, when a new one to carry a highway and one line of electric cars in the middle was erected under the direction of Mr. L. L. Buck. Other interesting suspension bridges in Canada are those at St. John, New Brunswick, also designed by Mr. Serrell, and one at Montmorency Falls, Quebec. The St. John bridge dates from 1852 and carries a platform 100 feet above the river, with a span of 640 feet. It has ten cables, and stone towers and was rebuilt in 1857. The Mont-

morency bridge was located just below the falls adjoining the residence of the Duke of Kent, but it collapsed some years ago carrying a wagon and its driver into the cataract 250 feet below, and only the stone towers now remain. The old Chaudiere highway suspension over the Ottawa river at Ottawa, Canada, was removed in 1888.

303. One of the first to propose open web, deep stiffening trusses braced together transversely for suspension bridges was John C. Trautwine, who in 1851 designed a bridge to cross the Delaware river at Market Street, Philadelphia, with four river spans of 1,000 feet each, and two end spans of 500 feet, using wire cables, and trusses 20 feet deep. His plan was exhibited for several months at the Franklin Institute in that city, and later at the Merchants' Exchange, from which hall it was removed without the owner's permission. Eighteen months after this a similar arrangement was proposed and used by John A. Roebling for the **railroad bridge** over the **Niagara river.** Lattice stiffening trusses, 6 feet deep, were used also on a railroad suspension bridge over the Kentucky river at Frankfort, Kentucky, which existed in 1852 and was built some years before with spans of 100, 261 and 200 feet. It had no stays and the floor was supported with rods 3 feet apart. Mr. Stephenson's tubular railroad bridge over the Menai Straits was also designed as a suspension with solid web stiffening girders, instead of open trusses, but as the girders were found to be strong enough in themselves, the cables were omitted. The Niagara bridge had a span of 825 feet with two decks, the lower one carrying a highway 15 feet wide, partially enclosed at the side by the timber stiffening trusses. The upper deck, 24 feet wide and 245 feet above high water, had a single track in the center and was floored over, separating it from the road below. The floors were suspended at intervals of 5 feet from the upper and lower cables.

the deflection of the lower one being 10 feet more than the upper one. There were four cables 10¼ inch diameter, containing 520 wires in each or a total of 3,640, the wires of Mr. Ellet's old foot bridge being incorporated with the others. The masonry towers were 60 feet high above the road, 15 feet square at the base, and 8 feet square at the top, and the bridge was braced laterally against wind pressure by 56 wire guy ropes, 1¼-inch diameter, fastened to rocks below, the guys detracting considerably from its appearance. It was commenced in September, 1852, and completed in 1855, at a cost of $400,000. In 1877 damaged wires in the cables were replaced with new ones and later the anchorages were strengthened, and in 1880 the old wood stiffening trusses and the floor system were removed and replaced with steel. At a later date some new stones were inserted in the towers, but in 1886-87 the stone towers showed further signs of weakness and were renewed in steel. Ten years later the whole bridge was replaced by the present steel arch, with a span of 550 feet. The history of railroad suspension bridges has not been satisfactory, for all have lacked stiffness and rigidity, and those at Niagara, Frankfort, Vienna and Durham over the Tees, have been removed. The modern advocates of stiffened suspension bridges declare their failure due to a lack of reliable theory for stiffening them, which theory has since been developed and explained.

The bridge over the Elk river at Lovell Street Charleston, W. Va., which collapsed December 15th, 1904, dates from 1851-52, and was designed by W. O. Buchanan, with Wm. Kuhn and Abraham Wright in charge of construction. After its collapse a careful investigation and report was made by H. G. Tyrrell (Engineering News, Jan. 5th, 1905), who made plans, estimates and tenders for replacing it with either simple spans, suspension or cantilever. The distance between tower centers was 478 feet and the floor, 17 feet wide, was on

a grade, being 7 feet higher at one end than at the other and 35 feet above water in the middle. The towers were 30 feet high above the floor, 30 feet on centers transversely at the low end, and 34 feet at the other end, supporting two 3¼-inch wire cables on each side, the whole costing $19,000. It was twice disabled by retreating armies during the Civil War and the last time was completely wrecked. Tolls were collected until 1886, but soon after being transferred to the city it was reported unsafe and failed under a load of 4 inches of ice and snow, carrying a large number of people and vehicles into the river, killing two persons and seven horses, and seriously injuring several other persons.* A similar suspension bridge at Morgantown, W. Va. (1855), has a span of 608 feet, supported by two cables, and another over the Gauley river in West Virginia, was used during the Civil War.

304. The first suspension bridge over the **Mississippi river** at **Minneapolis,** was built in 1855, with a span of 620 feet, connecting the west bank of the river with Nicollet Island, and was under the direction of Thomas M. Griffith, who was formerly associated with Mr. Serrell in the construction of the one at Niagara. The four cables containing 2,000 strands of No. 10 wire were supported on wooden towers composed of sixteen wooden posts of 12x12-inch timber, with a base 14 feet square. The cables had a sag of 47 feet and were cradled 10 feet, supporting a total load (including their own weight) of 92 tons. The floor was carried on white pine beams, 3½x14 inches, spaced 3 feet 9 inches apart with light stringers on top to support the plank. The width between centers of trusses was 17 feet and the cost of the structure $40,000. It is said to have been the first bridge of any kind over the Mississippi.

*Engineering News, Feb. 2, 1905.

305. A suspension bridge was started by Mr. Roebling in 1857, to carry the Cincinnati Southern Railroad over the Kentucky river at an elevation of 275 feet above the water, on the site of the present three span cantilever. The span of the cables was 1,230 feet, but after the towers were completed, building was discontinued, owing to the failure of the company. Another Roebling bridge, over the Allegheny river at Pittsburg, replaced an old wooden one of 1818. It had two river spans of 344 feet and two shore spans of 171 feet, or a total length of 1,030 feet. The deck, including two 10-foot walks, is 40 feet wide, with a floor on iron framing supported by four cables, two 7 inches and two 4 inches in diameter, dipping 30 feet and resting on cast iron towers 45 feet high. No important new suspensions appeared in America during the next ten years, until the opening of the bridge at Cincinnati in 1867, but in Europe there was at least one each year worthy of mention. **The Victoria suspension** bridge at Chelsea, by Thomas Page, connecting Battersea Park with Pimlico (1854-58), has central and end spans of 348 and 183 feet respectively, with a cable sag of 29 feet, supported on cast iron towers. The four flat eyebar chains support a deck 47 feet wide, with suspenders 8 feet apart. The road is 24 feet above high water and is cambered 18 inches to the center and stiffened with lattice girders 6 feet deep. It is 720 feet long, cost 112,100 pounds sterling, and is one of the cheapest and most attractive bridges in London. In strong contrast with the Chelsea bridge is the three span suspension bridge at Lambeth, designed in 1862 by P. W. Barlow, and costing 48,900 pounds, with a 20-foot road and two walks outside the trusses, or a total width of 32 feet. It stands on cylinder piers and has cables fixed at the top of towers, causing a pull on them from uneven loading of adjoining spans. In suspension bridges of several spans Mr. Barlow proposed to prevent deflection of

the loaded span by fixing chains rigidly to the towers and designing them as cantilevers to resist the tension from the chains. The **Clifton bridge** over the Avon at Bristol was finished by Messrs. Barlow and Hawkshaw in 1864, though it was commenced and the towers built in 1829-30. It has a single span of 702 feet, with a platform 31 feet wide and 252 feet above high water. Construction was resumed in 1840 by Brunel, but was not continued until the old Hungerford bridge at Charing Cross, London, was removed and the parts transferred to Bristol, and re-erected there in 1864 at a cost of $500,000. It has six chains, three on each side and was the longest span with flat eyebars in Europe.

306. In the years, 1860-64, two fine suspension bridges appeared in Vienna over the Danube. The first one (1860, Fig. 107) was the rebuilding of the old suspension in 1828, which had been in service for 32 years. The new one had a clear span of 255 feet and the cables were double lines of braced chains 4 feet apart. It was the first and only railway suspension in Europe, and continued in use for 25 years, when it was again replaced by the present arch. The Aspen bridge (1864) over the same canal at Vienna has a clear span of 200 feet, and braced chains similar to the last.

307. A new form of suspension (Fig. 112), which was partly a modification of that devised by James Dredge in 1832, was developed by **Rowland M. Ordish**, and several were built by him after 1868 on his principle. It had sloping rods running directly from the panel points of the floor system to the top of the towers, the direct tension members being supported and held in position by catenary cables between the towers, which have no other purpose than to sustain the weight of the direct tension bars. Bridges of this kind were built at Prague, London and Singapore. The Albert bridge over the Thames at Chelsea has a center span of 400 feet and

two side spans of 155 feet on the Ordish-LeFeuvre principle, begun in 1863 and finished 1873 at a cost of 117,200 pounds. The Franz Joseph bridge over the Moldau at Prague, designed by Rowland Ordish, 1868, with a center span of 480 feet and two side spans of 156 feet, has twelve main and two auxiliary chains with a sag of 60 feet, supporting a platform 32 feet wide on piers 16½ feet thick at the road level. The straight bars were replaced in 1898 by wire rope when the bridge was otherwise strengthened. The suspension foot bridge over the same river at Prague, Austria, erected by Ordish (1869), is located between the old stone bridge and the new suspension and succeeded a boat ferry. It has only one tower in the middle of the river, and is really two half spans of 305½ feet, with a clear distance between shore abutments of 629 feet. A single pier was believed to offer less obstruction to ice than two piers as ordinarily used, and was therefore adopted. The pier is of stone 18 feet thick at the floor level, and is surmounted with ornamental cast iron towers. Each column has four standards bolted to the piers and they are connected at the top with open cast iron girders. The clear width is 11 feet, the chains being placed a greater distance apart over the tower than at the abutments. The floor and tower top are 6½ and 63 feet respectively above high water. The chains which rest on a saddle with rollers, are steel links 4½ by 1 inch, 21 feet long, with heads and 3½-inch pins. The floor is supported by cast iron girders, 21 feet apart, suspended by wrought iron rods from the cables, and two continuous stiffening trusses add rigidity. The river banks are low, requiring twenty steps leading up to the deck at each end. The cost of the whole bridge was 18,500 pounds sterling. Mr. Ordish and Col. G. Collyer also designed and built a rigid suspension bridge on the Ordish plan at Singapore, capital of the Straits Settlements, on the island of the same name. It has

a span of 200 feet, a roadway 21 feet wide, and two sidewalks with wooden floor, and a total width of 31 feet. The stone piers extend up to the road level and the stiffening girders are 4 feet deep and 21 feet apart.

308. In 1840 Col. Charles Ellet made an offer to bridge the **Ohio river** at **Cincinnati** with a 1,400-foot suspension, 112 feet above the water, and he made a similar proposal in 1849. In 1846 John Roebling reported on a proposed bridge at the site, with a span of 1,057 feet as finally built, but his first plan had a tower in the middle of the river, which was not acceptable. The bridge was begun in 1856 by Roebling, but the financial panic of 1857 and the war delayed it until 1863, after which time construction was continued until its completion in 1867. At low water the Ohio river has a width of 1,000 feet, but in 1832 the river rose 62 feet above low water, and at this stage it had a width of 2,000 feet. The towers are 52x82 feet at the base and rise 75 feet above the floor, with transverse arches 30 feet wide over the roadway. The side spans from abutment to tower are 281 feet, making the total length of bridge 1,619 feet, and the total length over abutments 2,252 feet. It was the longest suspension bridge previous to the one at Brooklyn. The elevation of the floor above low water, is 91 feet at the towers and 103 feet in the middle. It has two wire cables 12½ inches in diameter, with a versed sine of 90 feet, with numerous stay cables and stiffening trusses 10 feet deep between the roadway and walks supporting a wood floor on steel framing. The bridge originally had a 20-foot road and two 7-foot sidewalks or a total width of 36 feet, and the cost was $1,828,000. In 1897-98 it was strengthened under the direction of Wm. Hildenbrand by the addition of two new steel cables, 10½-inch diameter, directly over the old iron ones, and increasing the width of road to 30 feet and the walks to 9 feet each, the cost of reconstruction being $650,000.

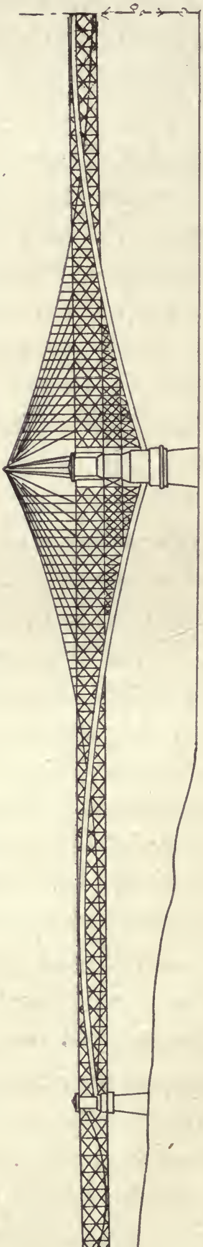


Fig. 113.

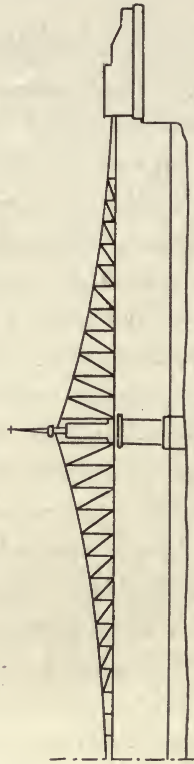


Fig. 114.

Fig. 112.

In the same year when the Cincinnati bridge was completed, Mr. Roebling made a report on bridging the North (Hudson) river at New York, and declared an iron wire suspension of 3,000-foot span to be practicable. A year later he prepared elaborate designs which were a combination of arch and suspension, with stiffening trusses and stay cables, for a proposed three span bridge over the Mississippi river at St. Louis, with a center span of 800 feet (Fig. 113), and published a book explaining and illustrating his design, but Mr. Eads arch bridge was accepted instead.

309. The **Niagara-Clifton suspension** bridge, located a short distance below the falls, was begun in 1867, under the direction of Samuel Keefer, civil engineer of Ottawa, Canada, and was completed by him twelve months later. It had a span of 1,260 feet between centers of wooden towers, and iron wire cables with a sag of 90 feet, 12 feet apart at the middle of the bridge and 42 feet apart at the towers, the cables being imported from England. The floor was 190 feet above water and was carried by vertical suspenders 5 feet apart. The stiffening trusses were 6½ feet deep and the bridge was further braced with 12 wire stays from each tower to the floor. There were also side guys anchoring the bridge to the shore and preventing excessive vibration from wind, and the original cost was 22,000 pounds sterling. The roadway had a clear width of only 10 feet, not great enough to permit carriages to pass, and in 1888 it was widened to 17 feet, alterations being completed in December of that year. On January 5th, 1889, it was blown down, but was replaced in four months' time by a new structure with steel wire cables, steel towers and stiffening trusses, and was re-opened to travel on May 7th, 1889. The whole bridge was replaced ten years later with an 840-foot steel arch.

310. The only new suspension in Europe at this time was

a foot bridge (Fig. 114) over the Main, between Frankfort and Sachsenhausen, designed by Schnirch in 1869, with stiff riveted members having part cantilever action. The Angarten bridge at Vienna, with a 202-foot span (1873), on the Fives-Lille system, is an interesting work and highly ornamental.

In the years 1870 and 1871, two new suspensions, with spans of 470 feet, appeared in the United States, the first, with two cables, being at Waco, Texas, over the Brazos river, and the second over the Allegheny in Warren County, Pennsylvania. The Waco bridge was designed by Thomas Griffith, engineer of the first one at Minneapolis in 1855. **The Minneapolis bridge,** after 20 years of service, was found insufficient for the increased traffic, and in 1875 was replaced by Mr. Griffith with a new and heavier one of 675-foot span. It had two main cables 10 inches in diameter, containing 3,648 strands of No. 9 wire, and two sidewalk cables 4 inches in diameter, containing 450 strands, with a sag of 58 feet and 6-foot cradling. The two lines of wood Howe stiffening trusses at each side of the roadway were 7 feet deep and two outer ones 6 feet deep, with four stay cables in each quarter, the total weight of suspension material being 350 tons. The cross floor beams were 3½x13½-inch white pine, 36 feet long, placed in pairs 5 feet apart. On these, stringers were placed covered with plank and a wood block pavement. The masonry towers were 111 feet high and 35 feet apart on centers, and the width between main trusses was 20 feet, with 6-foot walks outside. The two main anchors were solid stone, 10x10x40 feet, and the cost of the bridge proper was $127,000, and the approaches $72,000, or a total of $199,000. In 1888 a new steel arch was erected beside the suspension, and in 1890, when the arch was completed, the suspension bridge was removed at a cost of $3,000. A very unusual design was carried out in 1871 in the Redheugh bridge, 850 feet long, over the Tyne near

Newcastle, which is a combination of truss and suspension. It is supported on three braced towers and the upper and lower members of the truss are respectively gas and water pipes.

311. The **Point bridge** (Fig. 115) at Pittsburg was designed by Edward Hemberle, and built in 1876 with a center span of 800 feet and two side spans of 145 feet each, making a total length of 1,250 feet. It had a 20-foot roadway and two 7-foot walks with a clear height beneath of 80 feet and cost

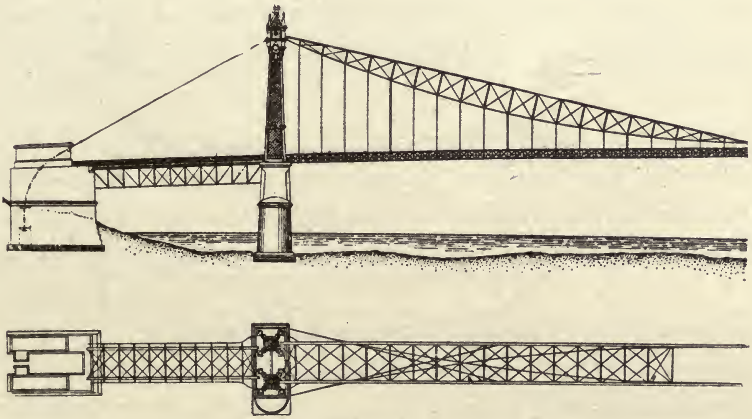


Fig. 115.

$525,000. The river piers were of stone and the towers of iron, 110 feet high. The 8-inch eyebar cables have stiffening trusses above the chains in the form of segmental chords, and the design is such that all uniform loads are carried by the cables, causing no stress in the stiffening trusses. It was the longest span with flat eyebars in America, and toll was collected upon it till 1896. In 1906 it was repaired at a cost of $92,000. Another suspension over the Allegheny at Oil City was built the same year, with a span of 500 feet, supported by two cables, but was rebuilt in 1884 and again in 1905. At Franklin, Pa., an unusual failure of a suspension was caused by fire in an

adjoining building, melting the lead which secured the cables into their iron sockets, and allowing them to pull out and precipitate the bridge into the river. The Mill Street suspension at Watertown, N. Y., with a span of 175 feet, was replaced in 1898 by a steel arch. The floor was 18 feet wide without stiffening and was supported by vertical rods from four main cables, each of which was 2 inches twisted iron wire rope, with a sag of 12½ feet. The 3 by 6 inch wood joist were carried on 9-inch beams.

312. Two bridges over the Allier river in France, which were built in 1879-84, had some interesting and unusual features. One at St. Ilpize (1879) had a center span of 232

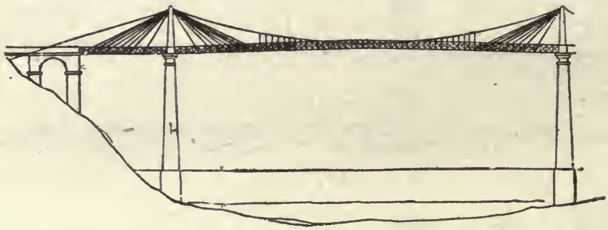


Fig. 116.

feet and side ones of about 50 feet, crossing the river at an elevation of 85 feet (Fig. 116). The floor load for a distance of 50 feet at each side of the cast iron towers was carried directly to the towers by inclined ways, and the main cables support only a portion of the platform in the central span. This arrangement of loading distorts the curve of cables from the catenary, but greatly reduces the amount of load upon them. The bridge is 13 feet wide, and the whole cost was $14,000. Similar bridges are at Lamothe, France, 1883-84, with a span of 377 feet, a width of 18 feet and cost $36,400; and another over the Saone at Lyons by Arnodin (1888), with a total length of 397 feet. A suspension foot bridge at Inverness over the river Ness (1877) has center and end spans of 173.

and 50 feet, respectively, supported on steel towers founded on cast iron piers filled with concrete. It has two wire rope cables 6 inches in circumference from which a 6-foot road is suspended with ⅝-inch rods, the cables being attached to concrete anchor blocks 10x10x26 feet. The steel lattice stiffening trusses are 4 feet 3 inches deep, and the whole bridge cost only $5,000. Several designs were made for suspension bridges to cross the Firth of Forth, and in 1880 a contract for construction was awarded on a design (Fig. 117) by Sir

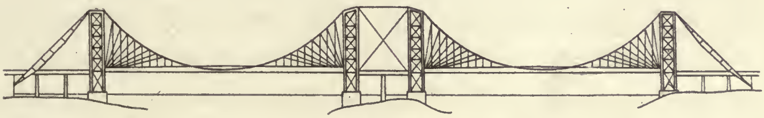


Fig. 117.

Thomas Bouch, with two spans of 1,600 feet, but the failure of the Tay bridge designed by him caused the Forth project on his plan to be abandoned, and a cantilever design by other engineers accepted instead.

313. For many years the most prominent object about New York was the old **Brooklyn bridge** (Fig. 118), crossing the East river from Park Row to Sands and Washington St., Brooklyn, and though there are now three others across the East river, the first is the most conspicuous from lower New York and from the harbor. The preliminary investigations and designs were made (1850-55) under the direction of John A Roebling, who died 1869, at the age of sixty, the same year that construction work was commenced, but it was carried to completion (1883) under the direction of his son, Col. Washington Roebling. The towers are 1,595½ feet on centers and each end span is 930 feet, with an approach on the New York side of 1,562, and a corresponding one at the Brooklyn side of 971 feet, making the total length 5,989 feet. The platform, which is supported by four main cables 15¾

inches in diameter with a sag of 128 feet, has provision for two elevated railroad tracks, two trolley tracks on the two 18-foot highways, and a center way of 15 feet for pedestrians, the total width being 85 feet. The stone towers, which are 53 by 136 feet at the roadway level, stand 278 feet above high water and the under clearance for ships is 135 feet. The original cost of the structure was $9,000,000, and of the land $7,000,000, making a total cost of $16,000,000, a large portion of which was incurred in financing the project, but many improvements and additions have since been made, increasing the cost to about $21,000,000. The cars carry 300,000 passengers daily over the bridge in addition to the travel on the carriage ways and foot paths, and plans have been developed for strengthening it and increasing its capacity by adding deeper stiffening trusses and an entirely new floor system. While the Brooklyn bridge was under construction, another one was projected to cross the East river at Blackwell's Island, New York. Cantilever designs were prepared by W. P. Trowbridge and Charles MacDonald, but a suspension bridge designed by T. C. Clark and Adolph Bonzano was accepted and a construction contract in the amount of about $5,000,000, was awarded in 1881 to Thomas Rainey of Ravenswood, Long Island. It had river spans of 734 and 620 feet over the two channels, a clearance beneath it of 150 feet and a total length of 9,000 feet, with suspension chains stiffened similar to the Point bridge, Pittsburg. The deck had provision for two tracks, two carriage ways and double foot walks, but the project was never completed and the site is now occupied by the Blackwell's Island or Queensboro cantilever bridge. To avoid long and expensive approaches to high level bridges in large cities, such as the East river bridges in New York, a plan was prepared in 1885 in which the ascent to the bridge floor was made on a street circling around outside of tower-

like abutments, the interior of which was arranged for shops, warehouses or offices. A bridge with rudiments of this idea was erected over the Mississippi river at Hastings, Minn., with a river clearance of 75 feet, and a spiral approach at one end.

314. The **Seventh Street bridge** over the Allegheny river, at Pittsburg, Pa., has three towers with two river spans of 330 feet and two shore spans of 165 feet with a 90-foot truss over the railroad tracks. It was erected in 1884 from designs by Gustav Lindenthal and has eyebar suspension chords composed of two lines of eyebars with diagonals between them. Its width is 42 feet and total length 1,080 feet, both chains being in tension from uniform loads. In the same year a light suspension bridge was built over the Elk river at Charleston, W. Va., with a span of 273 feet, adjoining the one which collapsed in 1904. It has twisted wire cables, back stays, lattice trusses and iron towers on high stone piers. A few years after it was completed, one anchor block moved slightly forward, allowing the tower to slope towards the river, but it was repaired by William Hildenbrand, who added new anchor masonry. For several years it carried a single line of track for light street car travel, but this was discontinued in December, 1904, when the adjoining suspension bridge fell. A careful examination of the bridge was made in January, 1905, by H. G. Tyrrell, and a report submitted to the city railroad company. The corrosion of the cables where they entered the masonry, which caused the wreck of the Lovell Street bridge at Charleston, also caused a suspension bridge at Ostrawitza, Austria, to fall in 1886.

315. Competitive plans submitted for the Washington bridge over the Harlem river in 1886 called forth two suspension designs by William J. McAlpine, with center spans of 800 feet, one of which had end cables loaded and an esti-

Fig. 118.

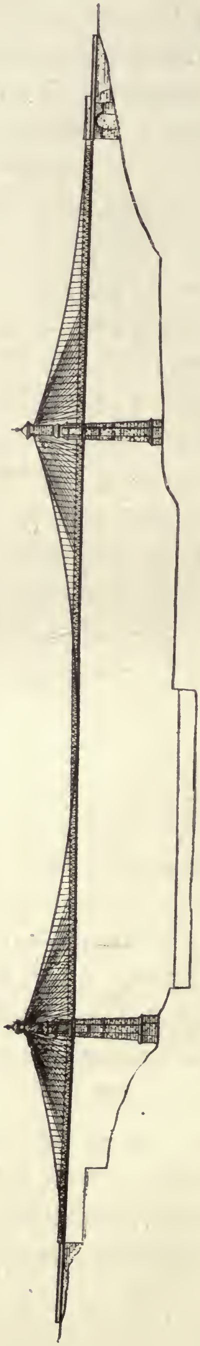


Fig. 119.

Fig. 120.

mated cost of $1,500,000 (Fig. 119); and another with ends unloaded and the road supported on masonry arches (Fig. 120) somewhat like the Menai suspension, with an estimated cost of $2,100,000. Other notable designs in 1886 were those proposed by Col. P. C. Hains, Capt. T. W. Symons and Mr. Paul Pelz, for crossing the Potomac at Washington with a span of 1,100 feet and two shore arms of 652 feet, carrying a platform of 54-foot width at a height of 105 feet above the river. The name of the proposed bridge was the "Grant Memorial," and the estimated costs $3,000,000 to $5,000,000, but none of the designs were ever built.

As suspension bridges can be quickly placed, they have frequently been used as **temporary structures** to replace others which have been washed away. They were used at Kansas City after the flood of 1904, and one was erected over the Tiber at Rome where the two arches of Ponte Rotto were swept out. Another at Rome (1889) has stiffened cables somewhat like those of the Point bridge at Pittsburg, excepting that both chords of the bridge at Rome are in tension under uniform loads, the curve of equilibrium passing half way between them, while under those conditions the lower cable only is in tension on the Pittsburg bridge.

316. Many of the largest suspension bridges in the United States span the Ohio river, and a very attractive one over one of its tributaries is about two miles from Valley Junction, crossing the Whitewater river with a span of 498 feet. It has ornamental stone towers 12 feet square at the base and 36 feet on centers, transversely, with a 20-foot clear roadway between them. The end cables are unloaded and the floor is braced with stays in the four quarters and held laterally with guys fastened to anchor blocks on shore. In strong contrast to this bridge was another over the same river at Richmond, Ind. (1889), with a center span of 150 feet and a total length of

200 feet, costing complete only $2,150. The towers consisted of iron pipe driven into the river bank, and the floor was supported by rods radiating from their tops, as in the Ordish system. Light lattice trusses served as railing, but a person at the center of the span could cause the bridge to spring a foot or more. Several so-called economical types have appeared in the United States in recent years, one of which on the Eddy patent with a 300-foot span over the Mojave river at Victor, California, the strength of which was questioned, fell in 1890 under a test load. Another suspension bridge in California, the design of J. M. Graham (1890), carrying a timber flume over Kings river on a span of 451 feet between towers, was first used without stiffening trusses, but when

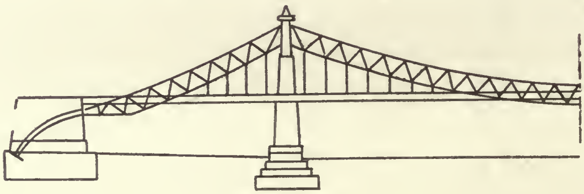


Fig. 121.

water was turned into the flume the load caused so great a waving motion of the floor that wood trusses at either side were added. It had seven 1⅜-inch steel cables at each side, which were covered with wood casing to prevent expansion from the excessive heat. Crude suspensions with floor on wire cables over temporary timber towers were used by contractors on the Union Pacific Railroad, to carry the track over ravines while embankments were being made. Car loads of earth were run out on the bridge and dumped into the valley below, the operation being repeated until the embankment was completed. A suspension foot bridge was placed across the Oapaaen river at the Odda works of the Alby Carbide factory, being similar to a type much used in Norway for foot

travel. Its four spans, the longest being 102 feet, are supported by three lines of 1¼-inch wire ropes passing over three timber towers, the cables being drawn taut and the wood floor laid directly thereon.

317. **Grand Avenue suspension bridge** at St. Louis (1890-91) designed by Carl Gayler is worthy of special mention (Fig. 121). It carries a street over the railroad yards with a center span of 400 feet and two end spans of 150 feet each. It is a three hinge inverted arch with two stiffened chains, one on each side. The upper chord and all web members are eyebars, while the lower chord consists of light riveted sections for stiffening purposes only, all uniform loads being carried by the upper bars. The width between center of

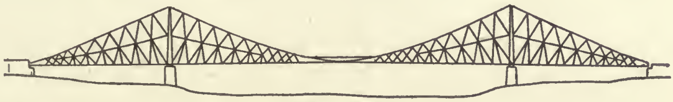


Fig. 122.

trusses is 42 feet, the total width 60 feet and the length over abutments 1,600 feet, the whole costing $450,000. Another long bridge over the railroad tracks at St. Louis, with a series of shorter spans, is lacking in stiffness due to their suspension or cantilever action. To avoid this lack of stiffness, Charles Steiner proposed in 1892 a combination of suspension and cantilever with short spans of 60 feet, supported by stiffened cables running direct to the top of towers. In alternate main spans were suspended trusses of 100 feet, and the arrangement of piers and general outline was somewhat similar to T. C. Clark's design of 1881 for the Blackwell Island bridge. Rigidity was secured by G. Koepcke in the **Loschwitz bridge** (Fig. 122), near Dresden, by using stiff members, and it is therefore sometimes called a cantilever. It has a central span of 481 feet and two side spans of 202 feet, with metal towers carrying a platform 36 feet wide. The curve of the upper chord

is a hyperbola, and as the center hinge transmits tension from one half to the other, it may be called a three-hinged suspension. It is very heavy and would easily carry two lines of railway. Conspicuous from its bright color of cobalt blue, it is commonly called "the blue wonder." Other bridges are at Vernaison over the Rhone, and Pont Lorois over the Etel. The first is 8½ miles below Lyons and is 1,283 feet long, with a center span of 763 feet and end spans of 172 and 139 feet suspended from wire cables. The platform, 17 feet wide, is supported at each side of the stone towers directly by stays from their tops, thus relieving the cables of much load. Pont Lorois on the road from Port Louis to Auray has a single span of 360 feet with stone piers and floor 40 feet above the water, but it was blown down in 1894. A park suspension bridge in the northeastern part of Paris, in the artisan district, has a single span of 200 feet, with three wire cables on each side supported on natural rock towers 17 feet high, with 10-foot openings blasted through to form the roadway portal. The towers are about 3 feet square at top and 8 by 20 feet at the bottom, and the cables are anchored back into native rock. The road, which is 12 feet wide and 40 feet above water, is stiffened with railing trusses 3½ feet deep at each side.

Suspension bridges are much in favor for park use, and artistic ones are found in the parks of Boston, Chicago and San Francisco. A small suspension in Mill Creek Park, Youngstown, with stiff eye bar cables, is the work of C. E. Fowler (1894). It has a span of 90 feet between towers, a road 20 feet wide, and two walks 5 feet each. (H. G. Tyrrell in American Architect, 1901.) The suspension bridge over a lagoon in the public gardens of Boston, adjoining the Boston Common, is probably as much seen as any object in the downtown district and is very artistic, as are also the more

recent ones in Garfield Park, Chicago, built in 1893, and Golden Gate Park, San Francisco. Oak Park, Illinois, had an unusual kind of suspension foot bridge, with a span of 125 feet, crossing the Desplaines river, with four cables ⅝-inch diameter hung between two trees for towers on the opposite banks, and was put up in 1887 by young men who at that time had little special knowledge of bridge building.

As material for suspension bridges is comparatively light and more easily transported than riveted structural work, many bridges in foreign countries, the parts for which are imported, have been made of this type. One of the largest of the kind is the Occidente suspension at Antioquia over Cauca river, Colombia, South America, which has a span of 940 feet, with the small cable sag of only 30 feet. The bridge is 12 feet wide, and has two 4-inch cables at each side with hollow towers, the lower 12 feet of which are of brick surmounted with timber frames. The height of saddles is only 22 feet, and as the bridge has a capacity of only 10 pounds per square foot, it is one of the very lightest ever made, and is remarkable for its extremely flat cables. Another bridge in Colombia over the Guarino river at Honda has a span of 130 feet, a road 12 feet wide and towers 16 feet high made of iron pipe filled with concrete. In the years 1895 to 1900 designs for several suspension bridges were made by the writer for export to Mexico and South America, mostly in small spans up to 250 feet. One for the Spanish Silver Mines at Mampimi, Mexico, over the Ojuela river (1900), has a span of 1,030 feet, supported by two wire cables on timber towers 50 feet high, and 30 feet on centers, with a 10-foot roadway. Each cable consists of three 2-inch steel wire ropes and in each quarter are four stays. A very light suspension somewhat similar to one at Fribourg, was placed across the Lehigh river at Mauch Chunk, Pa. (1888), to carry a six-inch oil pipe. The tower on one side

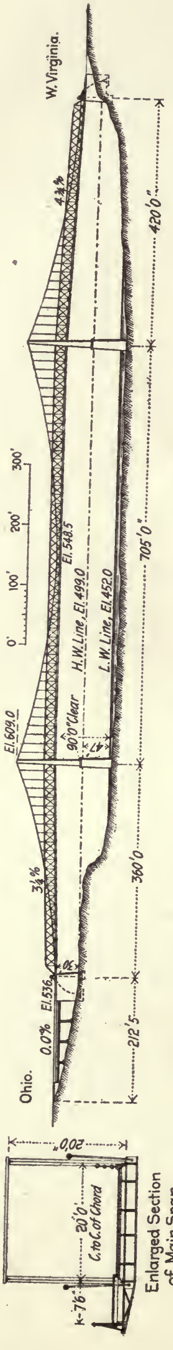


Fig. 123.

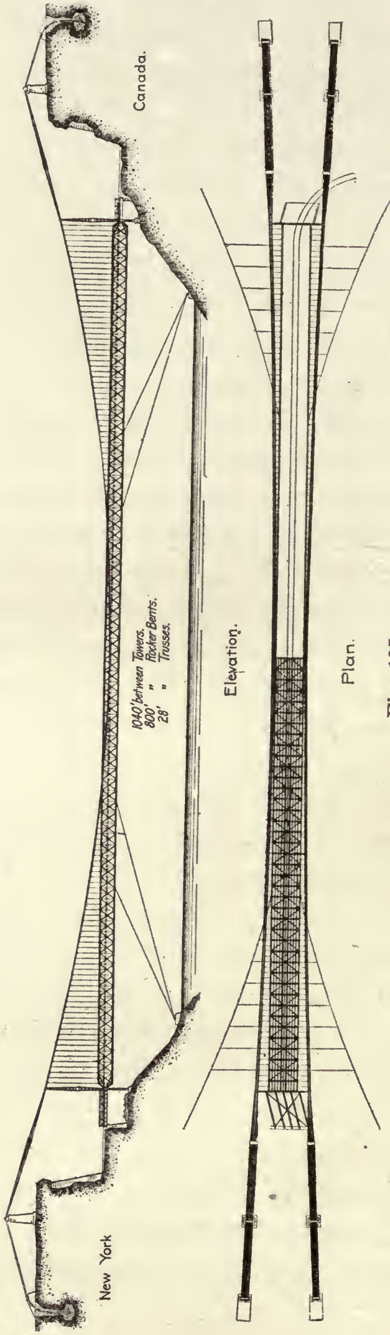


Fig. 125.

of the river is 115 feet higher than the anchor masonry on the other side, and the bridge floor, which is 360 feet long, is on a steep grade. It was the design of William Hildenbrand.

318. In 1897 two important structures very similar in design were erected over the Ohio river at East Liverpool, Ohio, and at Rochester, Pa., both having underneath clearances of 90 feet. The first (Fig. 123) has a center opening of 705 feet and side spans of 360 and 420 feet, with masonry piers 47 feet above low water, surmounted with steel towers 106 feet in height and 30 feet on centers transversely. It has a 20-foot roadway and a 7-foot walk on one side, with stiffening trusses 20 feet deep. The Rochester bridge has a center opening of 800 feet with side spans of 400 and 416 feet. The roadway is 22 feet wide with one 7-foot walk, and is stiffened with steel trusses 18 feet deep and supported by wire cables, the whole costing $175,000. The estimated cost of a cantilever bridge of the same size and capacity was $230,000. Similar to this was one proposed by Mr. Herman Laub in 1897, to cross the Ohio at Bellaire, with a center span of 850 feet, but it was not carried out. In the same year the competitive designs for a proposed bridge across the St. Lawrence river at Montreal brought forth two interesting suspension designs by J. W. Balet and C. C. Wentworth, with spans of 1,400 and 1,300 feet, respectively, a platform 105 feet wide and towers 300 to 400 feet high.

319. The Langenargen suspension on Lake Constance by Kubler (1898), 236 feet long, is a stiffened cable bridge with two cables 5¼ inches diameter of six twisted wire ropes, cradled from 22 feet apart at the center to 32 feet over the stone towers. The floor is stiffened with light side trusses and the end cables are not loaded. Floor stiffness is secured in the Muhlenthor bridge over the Elbe-Trave Canal at Lubeck (1899) by lattice ribs below the floor, and the Tower bridge

at London (1895) has stiffened end cables (Fig. 124). The competition for bridges at Bonn, Cologne and Worms evolved several interesting designs, one by M. Rieppel for Cologne having stiffened cables.

320. In 1899 when the two suspension bridges over the Niagara gorge, just below the falls, were replaced with steel arches, it was decided to use some of the cables from these

Fig. 124.

bridges for rebuilding the wrecked one two miles further down the river at Lewiston, and work was commenced the same year under the direction of L. L. Buck and his associate, R. S. Buck. The Lewiston bridge (Fig. 125) was the ninth to cross the gorge in the Niagara district, and is the only suspension now remaining there. It has a span of 1,040 feet with steel stiffening trusses 800 feet long, 14 feet deep and 28 feet

apart on centers, with a single electric car track in the middle and carriage ways on either side. It has four 10-inch wire cables, with guy ropes beneath the floor to prevent uplift from wind. The towers stand on rock cliffs high above the roadway, giving the bridge an unusual appearance. Another small ornamental suspension bridge crosses the rapid water between the two Sister Islands.

321. Two suspension foot bridges of the last decade, 6 feet wide, crossing the New river in West Virginia, are at Nuttallburg and Caperton. The first has a span of 340 feet supported by four cables 1¼-inch diameter, with masonry towers 22 feet high and 5 feet square at the floor level; while that at Caperton has a span of 510 feet and wood towers 19½ feet on centers transversely, 8 feet square at the base and 35 feet high, sheathed over and shingled. The platform is 50 feet above the water, which has a current of 10 miles per hour. The bridge has one cable 1½-inch diameter on each side.

322. A suspension bridge of very unusual design was erected over the **Lehigh river** and canal at **Easton, Pa.,** in 1900 (Fig. 126), from designs by H. G. Tyrrell. It is for pedestrian travel only and joins Dock Street on the lower side of the river with Glendon Avenue on the upper side, 90 feet above it. To overcome this difference in elevation of the two ends without incurring excessive expense for approach, the bridge floor was made to descend on a grade of 7.2 per cent from the upper bank to meet stairs rising from Dock Street at the lower side. The available revenue from tolls and the corresponding permissible investment were the governing considerations, and left no opportunity for artistic or architectural treatment. The bridge has two river spans of 279 feet, supported on steel towers 108 feet high, and a small tower at the upper end from which the cables pass over Glendon Avenue to their anchorages, the total length being 804 feet. It has

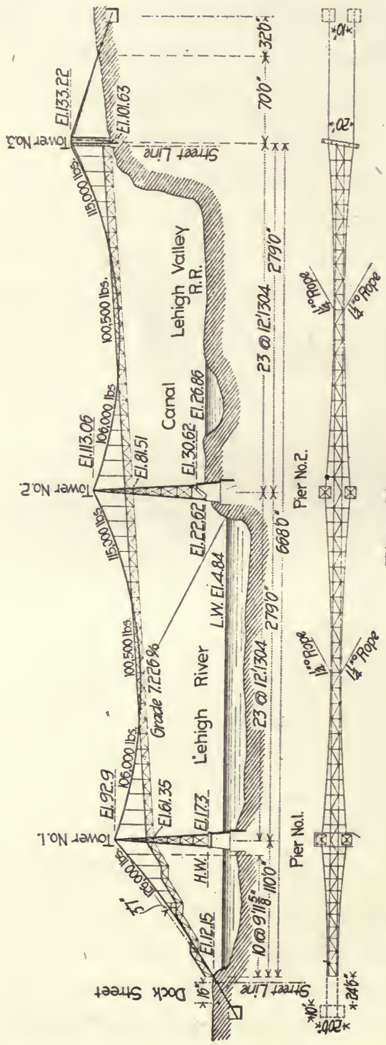


Fig. 126.

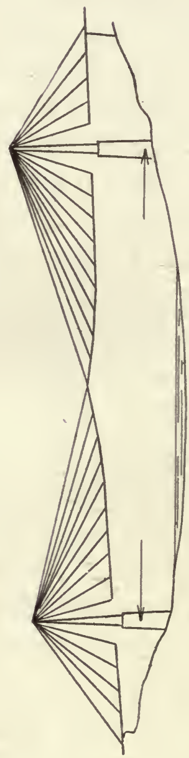


Fig. 127.

light stiffening trusses 5 feet 3 inches deep, suspended at intervals of 12 feet from the 2⅜-inch cables, which have a sag of one-tenth the span, the lowest point of the cables being 24 feet from the span centers. (Engineering News, Nov. 22, 1900, Scientific American Supplement, Sept. 28, 1901.)

323. Four years later another interesting one known as the **Ticonic** suspension **foot bridge** was erected at Waterville, Maine, at a cost of $18,000, carrying East Temple Street over the Kennebec river, with a center span of 400 feet. The platform was 6 feet wide and the distance between the towers transversely was 20 feet. It has a 2⅜-inch cable on each side, and the tower top is 72 feet above the water, the under clearance of the bridge being 30 feet. Two years previously the writer submitted several competitive designs for this bridge both with loaded and with unloaded cables. Another light bridge of this type was placed across the Merrimac river near Lowell, with a span of 550 feet. The cables, 2⅜-inch diameter, cradled from 24 feet apart over the timber towers to 6 feet at the center, leaving a clear foot walk of 4½ feet. Towers are 45 and 50 feet high and the cable sag is 36½ feet. It is the design of J. R. Worcester.

324. The new **Elizabeth suspension bridge** at Budapest (1905) is a model of elegance and simplicity. It has a single span of 951½ feet, a distance face to face of abutments of 1,235 feet and a total length over approaches of 3,014 feet, with piers 212 feet above zero water line. It has eyebar cables in vertical planes and steel towers 65 feet apart, pivoted at the base, enclosed by masonry, and was designed by Aurelius Czekelius, engineer, and M. Nagy, architect. A design which was submitted in 1897 by Kubler for this bridge had 120 feet of the river span adjoining each tower, supported on girders independent of the cables, the outer end of girders being hung from the towers. A suspension design submitted in 1904 for

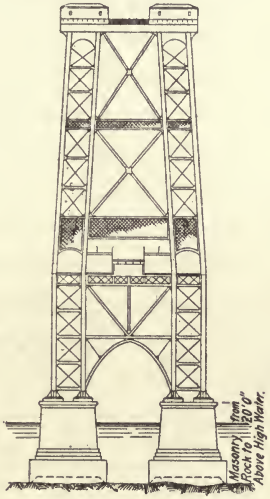
the Sydney harbor bridge had 1,300 feet stiffened center span, with end cables unloaded and approach spans on metal towers.

After several efforts to bridge the Mersey river at Runcorn, including suspension plans by Thomas Telford and Mr. Dumbell, and more recent arch designs of long span, a transporter bridge was erected there in 1904, with a clear span of 1,000 feet, and a clear height beneath it sufficient to allow the passage of ships with masts. Several other transporter bridges have their trolley ways and trusses suspended from cables, including several in France. The Runcorn bridge has cast iron towers 190 feet high on each side of the river, and the final cost of the structure, including power house and equipment, was $650,000, which was only one-third the estimated cost of a permanent high-level bridge of the same capacity and span, with the necessary approaches. A 70-foot car accommodating 300 people and four double horse wagons makes ten trips across the river per hour, or a single passage in 2¼ minutes. The new **Borsig suspension** over the Spree at Berlin, with stone towers of unusual design and eye bar chain cables is the work of Bruno Mohring, and leads to a new land tract that was lately opened.

325. Another recent electric railroad bridge, at Villefranche-de-Conflent, with a central span of 156 meters, and two end spans of 39 meters, has a platform supported by a system of cables running straight from the panel points of the floor to the top of the tower, somewhat similar to the Ordish principle. It has steel towers on masonry piers built up to the roadway level, and cost $76,000. Several similar to this, of the Gisclard type (Fig. 127), in spans up to 42 meters, have been exported and erected in the French Congo.

326. The **Williamsburg bridge** (Fig. 128), over the East river at New York, is the longest suspension, having a span of 1,600 feet between tower centers, and about 5 feet greater

than the old Brooklyn bridge. Its total length is 7,200 feet and width 118 feet. The underneath clearance for the passage of ships in the central 400 feet is 135 feet. It has two decks with provision for four trolley tracks, two elevated tracks, two foot walks and two carriage ways on projecting brackets. The two riveted stiffening trusses are 40 feet deep and 72 feet apart on centers, while the approaches have grades of 3 per cent, and the elevated tracks grades of 2 per cent. There are four main cables 18 inches in diameter, which are



Elevation of Tower.
Fig. 128.

335 feet above mean water at the top of towers, and the end spans are not loaded. The bridge passes from Delancy street in Manhattan to Broadway in Brooklyn, the distance from center of steel towers to anchor masonry at each end being 600 feet, divided into two spans of 300 feet each. The approaches cross over one and a half miles of streets and buildings. The 1,600-foot span weighs 8,000 tons, its greatest live load is 4,500 tons, and in each of the towers are 3,000 tons of steel. It has the largest traffic of any bridge in existence,

and is surpassed in length only by the Forth bridge in Scotland. The bridge proper cost about $8,000,000, and the land $12,000,000 more, or a total of $20,000,000. The chief engineer on construction was L. L. Buck, and O. F. Nichols, principal assistant.

327. The **Manhattan bridge** (Fig. 129), situated one-quarter of a mile east of the first Brooklyn bridge, has the largest carrying capacity of any bridge in existence. It was originally designed as a stiffened chain cable suspension, but a change of administration caused the eyebar cable plan to be abandoned, and wire cables adopted instead. The center and side spans are 1,470 and 725 feet, respectively, and the total length over approaches 6,855 feet, total width 120 feet, and towers 322 feet above high water. Each tower is composed of only two legs, approaching the condition of rocker towers, as on the new bridge at Budapest. The lower deck has provision for four surface tracks, one 35-foot carriage way, and two 11-foot walks, and the upper deck has space for four elevated railroad tracks. The cables are 21¼ inches diameter, hanging vertically, and the total cost about $26,000,000. It was openea to travel in December, 1909. All the East river bridges are crowded with travel, and it was proposed by Mr. T. K. Thomson that the approaches in Manhattan be connected to avoid the terminal features. Mr. Lindenthal's proposed design for the Manhattan bridge (Fig. 130) had four lines of stiffened cables fastened to the top of steel rocker towers 300 feet high, with one highway, four tracks and two walks on the lower deck, and four lines of elevated track on the second deck. He made a similar design for the Quebec bridge with end and center spans of 680 and 1,800 feet.

328. The proposed North or **Hudson river bridge,** with a span of 3,100 feet, which was seriously considered for fifteen years or more, would exceed any suspension yet projected,

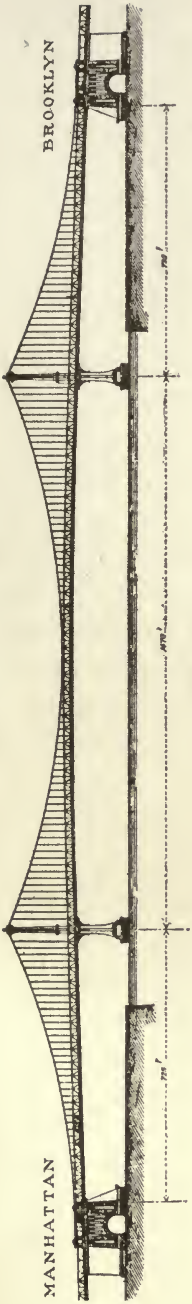


Fig. 129.

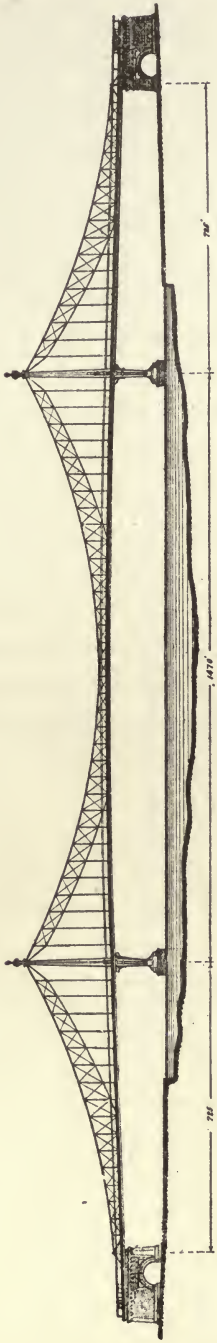
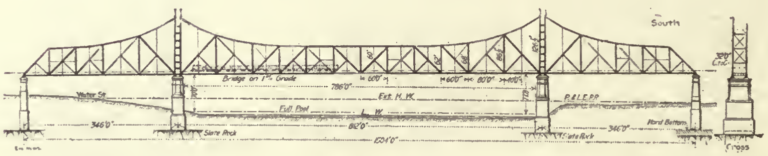


Fig. 130.

Fig. 131.

though a cable span of 4,427 feet between towers, consisting of four ⅞-inch galvanized steel wire cables, is in use at the Straits of Carquinez, California, 140 miles from Oakland, for the transmission of power, with a clear headroom beneath it of 200 feet. A commission of army engineers reported in 1894 that a span of 4,335 feet was practicable for bridges, and Mr. Lindenthal considers that this length may safely be increased to 6,000 feet for a bridge to carry heavy trains at high speed. At least five designs for the proposed North river bridge have appeared, with estimated costs of seventeen to thirty-seven million dollars. The one by Gustav Lindenthal, with stiffened eyebar cables (Fig. 131), and center and end spans of 3,100 and 1,800 feet, respectively, had upper and lower decks, and towers 600 feet high, carrying fourteen lines of railway track. The estimated cost of the bridge alone, without land, is $25,000,000. More careful investigations of the sites for foundations, show that solid bottom could be reached only at so great a depth as to make the project impracticable, and tunnels have been constructed under the river instead.



CHAPTER XIII.

CANTILEVER BRIDGES.

329. An essential difference between suspension bridges and cantilevers is that the former transmit tension across from one half to the other, while the halves of cantilever bridges are self-supporting. The earliest recorded cantilever bridge is at the sacred city of Nikko, in Japan, and dates back to the fourth century, A. D. It is known as **Shogun's Bridge,** and records state that "the abutments are of hewn stone, the shore piers of hewn granite, octagonal, monolithic, mortised for stone girders, and monolithic plate beams receive the wooden superstructure. The stringers, which are fastened into the abutments, balance over the stone beams, but do not reach by a considerable distance, the gap being fitted by middle stringers let into the stone stringers. It is not used by the laiety." A timber cantilever, also in Japan, in the province of Etchin, dating from 1665, had six lines of slanting timbers, cantilevering out from the opposite sides of the river, with intermediate stringers supported between the projected ends. The banks on either side were protected by large stones held in place by bamboo lattice work. A somewhat similar cantilever bridge (Fig. 132) at **Wandipore, Tibet,** (1650) had a span of 112 feet and lasted for one hundred and fifty years. It was made of fir, fastened together with wooden pegs without nails or metal of any kind. The cantilevers projecting about 40 feet out from either side were layers of timber keyed together, the upper courses in each case projecting out past the one beneath it,

and the space between the cantilever ends was spanned by simple timber beams. A smaller opening at one side had a single cantilever only, with end towers and entrance gates. Another but ruder bridge of this type spans a gorge in the

Fig. 132.

Himalayas near Darjeeling, India, on the border of Tibet, and still another is located near Opdal in Norway. Several interesting rustic cantilever bridges made by the Canadian Indians have been found in British Columbia, one of them

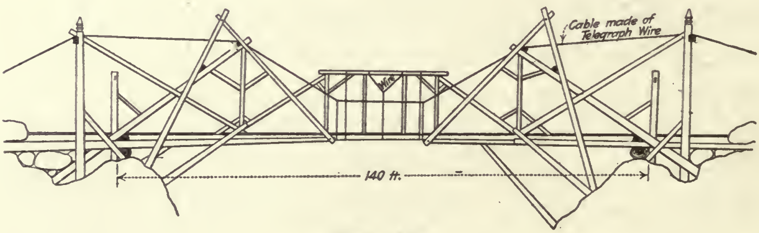


Fig. 133.

over the Bulkley river (Fig. 133), two hundred miles from Prince Rupert, containing a suspended span. A native cantilever bridge near Ona, Ecuador, has a floor of logs supported on projecting brackets at either side of the ravine.

In Colima, Mexico, a bridge (Fig. 134) was found spanning the Armeria river with a length of 175 feet. It was made by a native Mexican peon, who is reported to have seen a picture of a suspension bridge in an illustrated paper, and after examining the picture carefully concluded that he could build a similar one. His was a combination of cantilever and suspension with a clear span of 70 feet, the joints being put together without nails. The cables were made of twisted vines, and lighter or smaller vines were used in making the joints. Poles with natural forks or crotches driven into the river bank constituted the towers, and these were protected by a square enclosure of other poles and stakes tied together with rods and vines, the enclosure being filled up solid with loose

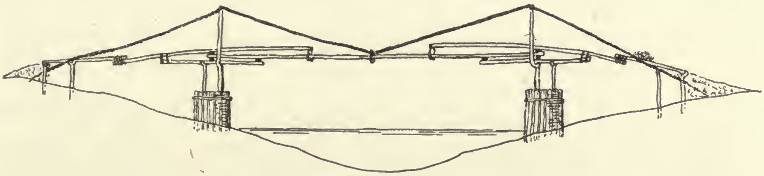


Fig. 134.

stones and gravel. The two main stringers were spliced at the middle, and supported at the center from the cables, and at the ends in crotches of the shore towers. The stringers were further supported at the quarter points by cantilever poles bearing on the towers and anchored with stones on shore. The bridge was strong enough to carry loaded mules and men on horseback, but was washed out by a freshet within a year after its completion. Undaunted by its failure, the peon bridge builder replaced it with another, which lasted eighteen months when it, too, was destroyed.

330. In 1810, Thomas Pope, a clever and ingenious carpenter of New York, made a 50-foot model to the scale of ⅜ inch to 1 foot for a proposed "Flying Lever Bridge" of 1,800-foot span to cross the Hudson river near that city. He

made elaborate plans and estimates and the following year wrote and published a book describing his invention. In 1833 patents were granted to Mr. A. Canfield on a bridge which contained elements of the cantilever principle. Twelve years later, when designing the Britannia bridge over the Menai Straits, 1845-47, Robert Stephenson evolved a plan with two cast iron arches of 450 feet flanked with half arches at the shore ends, and proposed erecting them from the three piers by placing sections symmetrically on either side, cantilevered out from the piers and tied together above them with ropes or rods, similar to the method proposed by Mr. Brunel for erecting masonry arches without falsework. The plan was not adopted for the Britannia bridge, but a similar method was used in 1867-70 in erecting the steel arches of the Mississippi river bridge at St. Louis. This was the first practical application of the cantilever principle in modern bridge building. It was used with the evident purpose of avoiding the expense of temporary staging, a reason which is still the governing factor in the selection of a cantilever bridge.

331. In the year 1850, Sir John Fowler had a wooden model made of a continuous girder with the chords cut at the points of contraflexure for the purpose of showing the merits of continuous girders and avoiding the uncertainty of their reactions. The Boyne river viaduct at Drogheda, Ireland (1855), had three continuous lattice spans with center and end openings of 267 and 141 feet respectively. The upper chords of the middle span were disconnected after erection, at the two points of contraflexure, 170 feet apart, but were afterwards riveted together again. In connection with Sir Benjamin Baker, Mr. Fowler made a design, in 1864, for a metal cantilever bridge with a span of 1,000 feet to cross the Severn. The span length was afterward reduced to 600 feet and a contract

awarded for its construction, but the failure of the company caused the project to be abandoned. Two years previous to this, Professor Ritter of Hanover computed the stresses for a 525-foot cantilever, and proposed, as did Mr. Fowler, to avoid the uncertainty of continuity by cutting the chords. During the same year Mr. Baker wrote his book, entitled "Long Span Bridges," in which the cantilever principle was considered. Messrs. Baker and Fowler designed another

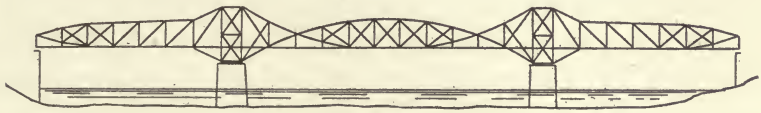


Fig. 135.

bridge, in 1871, to cross the Severn, this one having two cantilever spans 800 feet long, and two years later Mr. Baker designed a ferry bridge over the Tees, including a 650-foot cantilever.

332. In 1867 the three span cantilever bridge was built over the Main at Hassfurt (Fig. 135) from designs by Herr Gerber, with a central opening of 124 feet. During the years 1865-70 many combination cantilever and suspension bridges

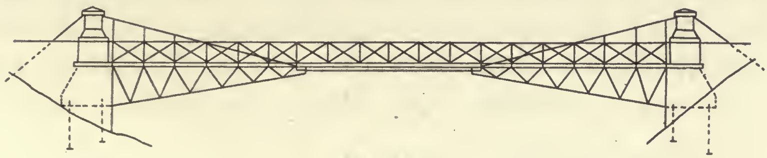


Fig. 136.

were built by Mr. A. Smedley, an English engineer, the bridges being known as "the Smedley System," one at Calcutta (Fig. 136) having a span of 75 feet. In the same years pamphlets were circulated by a company in America showing bridges in course of erection (Fig. 137), the parts being built out from shore without the use of falsework. Many crude ones were built throughout New England and

New Brunswick (1867-70) by the "Solid Lever Bridge Co.," of which C. H. Parker was engineer, the company being succeeded by the National Bridge and Iron Works.

In 1868 Prof. W. P. Trowbridge of Columbia College designed a cantilever bridge to cross the East river and

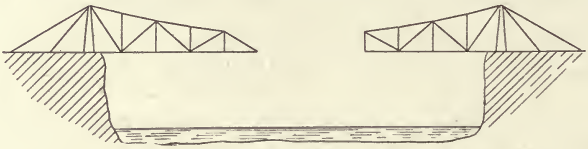


Fig. 137.

Blackwell's Island, New York, with channel spans of 600 and 720 feet and a clearance for ships of 135 feet. His plan showed stone abutments and metal towers, with numerous stays supporting the floor, and intermediate spans between

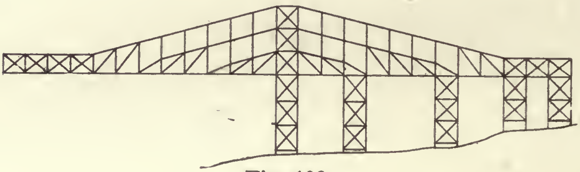


Fig. 138.

the cantilever parts. His design was revised in 1870, and in 1872, when an effort was made to finance the enterprise, the competition, for which prizes were offered, resulted in the acceptance of a design (Fig. 138) by Charles MacDonald,

Fig. 139.

president of the Delaware Bridge Co. It had two channel spans of 734 and 618 feet and an estimated cost of $3,000,000. The Wrsowic bridge on the Francis Joseph line of railway, designed by Joseph Langer in 1870, has three continuous lattice girder spans, stiffened by an upper member, following

the line of a suspension cable, but the **first railroad cantilever** bridge (Fig. 139) really built was over the river Warth at Posen, Poland, in 1876, with five spans, the center one 148 feet long.

333. In the same year, the **Kentucky river bridge at Dixville, Ky.,** (Fig. 140) was completed for the Cincinnati, Southern R. R. from designs by Charles Shaler Smith. It had three spans of 375 feet on metal towers, with a deck 275 feet above water. It is located at a place where a suspension bridge was started by John A. Roebling, twenty-two years before. To avoid the use of expensive falsework, the first section and the end spans was cantilevered out from shore

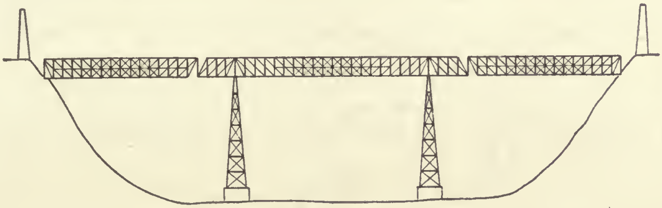


Fig. 140.

by tying the top chords back through the old piers of the proposed suspension bridge. Single timber towers were then built up from the valley in the middle of the end spans, the timbers being lowered from the overhanging trusses, and the erection of the girders was continued, cantilevering them over the timber towers to the permanent metal ones, and on further, to meet in the center of the middle span. After completion, the chords were cut 75 feet shoreward from each tower, making end spans of 300 feet and a center continuous girder 525 feet long. The girders are 37 feet 3 inches deep, 18 feet apart and 1,138 feet long. The heights of the towers and masonry piers are 177 feet and 71 feet respectively. There were 1,426 tons of iron in the spans and 400 tons in the towers. The trusses were replaced in 1910 by heavier ones

70 feet deep for double track, on wider towers and foundations, the deck being 30 feet higher than the old one, thus eliminating approach grades of one per cent at each side. On the reconstruction, a single lune-shaped two-hinged arch of 864 feet and 162-foot rise was considered, and partial plans prepared for erection at a new location, but the government requirements, that the old piers should be removed if not required, made the cost of the arch project greater than renewal with trusses on the old site. The rebuilding was under the direction of Gustav Lindenthal. Mr. Smith designed and built, in 1880, a similar but smaller bridge (Fig. 141) over the Mississippi river at St. Paul, with two end spans of 272 feet, and a center span of 324 feet, on iron towers. The trusses were 18 feet apart, 30 feet deep, and carried a single track at an ele-

Fig. 141.

vation of 100 feet above the water. The chords were cut in the middle of the center span, and there were, therefore, no suspended trusses. This bridge was replaced in 1901 under the direction of Mr. Onward Bates, by a double track bridge on stone piers. A highway bridge was built the same year over the Mississippi river at Fort Snelling with the largest span suspended from cantilever brackets on the two adjoining ones. The work was done under the direction of John S. Sewell, engineer of St. Paul, at a cost of $108,000. But Shaler Smith's largest cantilever bridge was the steel one over the St. Lawrence river at Lachine, Canada, carrying a single track of the Canadian Pacific Railroad (1888). It is 3,535 feet long, or only a little more than half as long as the Victoria bridge for the Grand Trunk Railroad, a few miles farther down the river.

334. The Lachine bridge at Montreal is notable chiefly for the method used in securing clearance over the channel, by changing two spans from deck to through trusses with graceful curves at the point of junction over the piers. The two center spans of 408 feet and the adjoining ones of 269 feet are continuous over five piers and were erected as cantilevers; but the remaining eight spans of 240 feet are simple trusses. The river has a depth of 20 to 90 feet and a current of eight to twelve miles per hour, making the foundations expensive, the whole bridge costing $1,250,000, or $354 per lineal foot. The continuous trusses are 20 feet apart on centers, and until recently were the longest of their kind, but the fixed spans are decreased to 16 feet for single track. It is now (1910) being replaced by a double track structure with simple trusses.

Fig. 142.

335. The first example of the modern metal cantilever bridge with suspended span was at Niagara (1883), to carry two tracks of the Michigan Central Railroad over the Niagara river at a height of 245 feet above the water (Fig. 142). It is two miles below the Falls, at a place where the gorge is 850 feet, and the river 425 feet in width. There were originally only two vertical and parallel trusses 28 feet apart, supported on iron towers. The top chord eyebars are of iron, and the bottom chord compression members of high carbon steel. In 1899, the bridge was strengthened by the addition of a third line of trusses placed midway between the others, supported on additional columns in the towers. The distance between centers of towers is 495 feet, and from the center of each tower to the end of shore arm is 207 feet 6 inches, making the total length 910 feet, the center suspended span

being 120 feet in length. The original cost without approaches was $600,000. It was designed by C. C. Schneider, but the reconstruction was done under the direction of Alfred Noble, consulting engineer, and A. Torrey and Benjamin Douglas, engineers for the railroad company. A similar bridge was designed by Mr. Schneider in 1884 to carry a single track of the Canadian Pacific Railroad at a height of

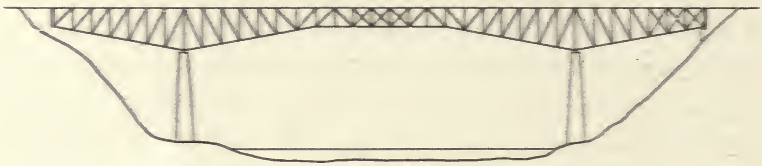


Fig. 143.

125 feet above the Frazer river in British Columbia (Fig. 143). The anchor and cantilever arms are each 105 feet long, with suspended span of the same length in the middle, making the distance between stone piers 315 feet. The superstructure containing 612 tons of metal was brought from England and erected under the supervision of Joseph Tomlinson, bridge engineer of the Department of Railways and Canals of Canada. The Gouritz bridge, Cape Colony, by Sir Benjamin Baker, is

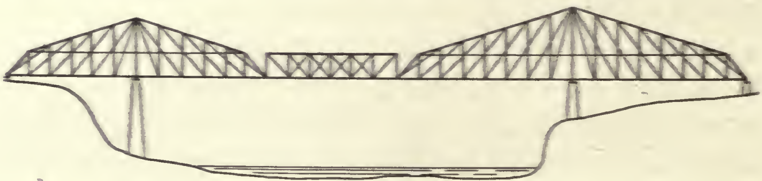


Fig. 144.

almost identical in outline to the Niagara cantilever, but with fewer panels and metal piers instead of wide braced towers. The bridge at St. John, New Brunswick (1885) is similar to that at Niagara, but with trusses inverted, making it a through instead of a deck bridge (Fig. 144). It carries a single track of the Canadian Pacific Railroad at an elevation of 96 feet

above low water. The cantilevers are of different length, making the bridge as a whole unsymmetrical, and the appearance is further injured by the presence of several trestle bents at the west end. It is 813 feet long and 477 feet between centers of stone piers. The trusses are 20 feet apart, with depths of 65 and 80 feet. It was built by the Dominion Bridge Co., of Montreal, G. H. Duggan, chief engineer.

The long viaduct carrying Eighteenth Street at St. Louis over the railroad yards near the Union Depot was designed on the cantilever principle. It has iron towers on stone piers with intermediate suspended spans and was completed in 1884, but has always been lacking in rigidity and is not satisfactory for heavy loads.

336. Many of the largest cantilever bridges such as those at Louisville, Poughkeepsie, Cernavoda, Memphis, Forsmo,

Fig. 145.

and Thebes have a series of alternate anchor and cantilever spans. The **Louisville bridge** (Fig. 145) carries both railroad and highway travel and was completed in 1886. The central 360-foot span, 65 feet deep, serves as anchor for the cantilever arms, and the two adjoining spans which are 480 feet between piers, each contain a suspended span 160 feet long and 28 feet deep. The cantilever portion is symmetrical about the center, but the bridge contains also a 370-foot draw and a 240-foot fixed span. The width is 24½ feet between trusses and 49 feet extreme. It was rebuilt for double track in 1910, to sustain live loads equal to Cooper's E 65 specification, the work being under the direction of W. M. Mitchel. The **Poughkeepsie bridge** over the Hudson (Fig. 146) was completed in 1889 and is owned by the Central New

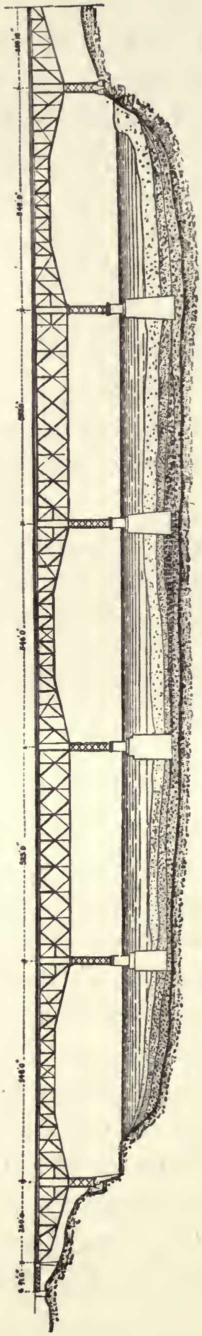


Fig. 146.

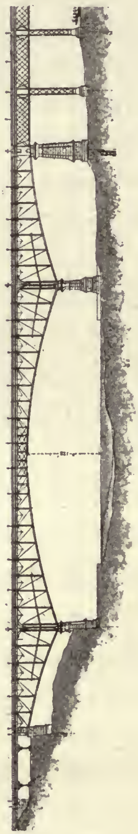


Fig. 147.

Fig. 148.

England Railroad Company, but leased to the New York, New Haven and Hartford Railroad Company. It has two anchor spans of 525 feet and three alternate cantilever spans of 548 feet, with a 200-foot shore span at each end. The total length is 6,747 feet, including approaches of 2,640 feet at the east and 1,033 feet at the west end, with the deck 212 feet above water. There were two tracks and originally only two lines of trusses 30 feet apart, but in 1906 it was strengthened by inserting another line of trusses midway between the original ones and adding new columns in the towers. The longer approach spans were also reinforced and the shorter ones replaced with new plate girders. The towers are 100 feet in height, standing on stone piers, supporting trusses 37 to 57 feet in depth. Water

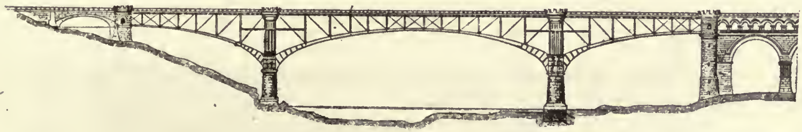


Fig. 149.

under the long spans is 60 feet deep, making the cost of false-work excessive, and the reinforcing required 15,000 tons of steel, and cost $1,300,000, the work being done under Mr. Mace Moulton.

337. Many of the most interesting cantilever bridge designs are the result of competitions. Among these are the bridges over the Harlem river and at Blackwell's Island, New York, at Mannheim and Budapest in Europe, and at Detroit, Montreal and Sydney, Australia. The Harlem river (Washington) bridge competition in 1886 brought forth four cantilever designs deserving of special mention, made by Messrs. A. P. Boller (Fig. 147), W. J. McAlpine (Fig. 148), Edward Shaw (Fig. 149), and Wilson Brothers, with estimated costs of about one million dollars. These designs, while unsym-

metrical as a whole, owing to the contour of the ground, contained symmetrical cantilevers. A design made by Mr. Schneider in 1887 for the proposed Blackwell's Island bridge (Fig. 150), between 64th and 65th Streets, had two channel spans

Fig. 150.

of 810 feet on metal towers 110 feet high, with a clearance beneath the spans of 135 feet for ships. The promoter of the enterprise was Dr. Rainey of Ravenswood, who had it proportioned for two lines of railway only. The cantilever

Fig. 151.

proper was 2,760 feet long and the whole bridge including approaches contained 26,000 tons of steel, 25,000 cubic yards of masonry and 3,000,000 feet of lumber. A very different design to the rest was submitted by George E. Harding, with a

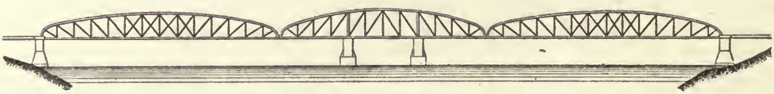


Fig. 152.

parabolic center span somewhat similar to the Hassfurt bridge. (Fig. 151).

338. Two notable cantilever bridges were built in British India 1886-1890, one over the Hoogly river and the other over

the Indus. The **Hoogly or Jubilee Bridge** (Fig. 152), by Sir Bradford Leslie, carries two tracks of the East India Railway at a height of 53 feet above the water. The central continuous trusses are 360 feet long and 50 feet deep, on cylinder piers 120 feet apart on centers, the cost complete being $1,305,000. The ancient and barbarous custom of offering sacrifices to rivers when bridging them continued in many countries and until the nineteenth century. When building the Hoogly bridge over the Ganges, the natives believed that mother Ganges had consented to be bridged only on condition that each pier be founded on a layer of infants' skulls. But when a new bridge was placed over the Arcen, twelve sheep were slain and their heads placed under the foundations. The **Sukkur bridge** (Fig. 153), over a branch of the Indus river, was designed by Sir. A. M. Rendel, engineer for the Indian Govern-

Fig. 153.

ment, with single 820-foot cantilever and a suspended span of 200 feet between 310-foot arms. It carries a 5½-foot gage track from Kurrachee to Attock, and cost $926,000, the high cost being partly due to the supposed necessity of erecting it at the shops in England before shipping to its destination.

339. The Stephanie bridge over the Danube Canal at Vienna is a cantilever with flat arched center span of 197 feet, and side anchor arms of 49 feet concealed in the abutments. The Warnow bridge near Rostock (1885) has a parallel truss over center piers with a single hinged panel at each end.

340. A bridge of unusual interest on account of its historic site is the cantilever (1886) carrying **Market Street** over the

Schuylkill river at Philadelphia. It replaced an old wooden truss of 1876, which succeeded Timothy Palmer's three span "Permanent Bridge." For this location, Thomas Paine, the noted writer, designed a 400-foot cast iron arch, the model of which he submitted (1787) to the Academy of Science in Paris. The cantilever bridge has a length of 538 feet, and extreme width of 77 feet and a buckle plate and asphalt floor. The river piers are 214 feet apart on centers and stand on the old "Permanent Bridge" foundations.

341. Cantilever highway bridges over the Mississippi river were built at Muscatine, Iowa (Fig. 154) (1889), with a span of 442 feet; Wabasha Street, St. Paul, the same year, with a

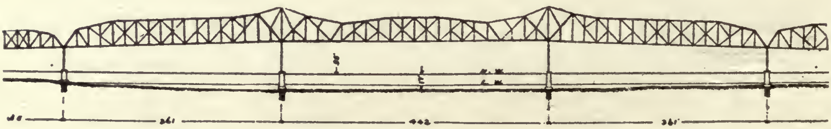


Fig. 154.

span of 280 feet, and one three years later at Clinton, Iowa (Fig. 155), with curved top chords over the piers. The Broadway bridge at St. Paul has a three span cantilever with two simple spans at one end, and one at the other, in addition to

Fig. 155.

some approach viaduct. The deck has a central roadway 31 feet wide with 11-foot walks on each side. The center trusses which are 55 feet deep are continuous over the middle pier, with extension arms supporting simple spans at the sides.

342. Several notable railroad cantilevers appearing between 1888 and 1892 are those at Point Pleasant, Tyrone, Red Rock, and two over the Verrugas and Pecos rivers. The

Point Pleasant bridge (Fig. 156), over the Kenawha river at Parkersburg, West Virginia (1888), is a through railroad

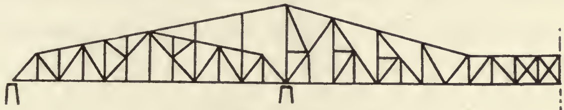


Fig. 156.

cantilever with a center span of 485 feet. It has 240-foot anchor arms, 200-foot suspended span and a total length of 960 feet, the whole containing 1,000 tons of steel. The bridge at **Tyrone, Ky.** (Fig. 157), over the **Kentucky river** (1889), conveys a single line of the Louisville and Southern Railway

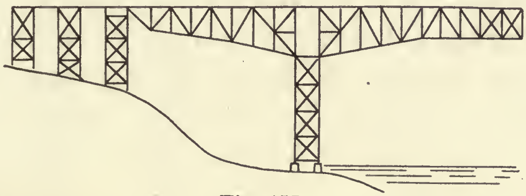


Fig. 157.

on a deck structure similar to that at Niagara, with a span between towers of 551 feet. Up to the date of its construction it was the largest and highest cantilever in America. The trusses are 24 feet on centers, the cantilever portion 998 feet long, with 210 feet of trestle approach at one end, and 390 feet at the other end, making the total length with approaches

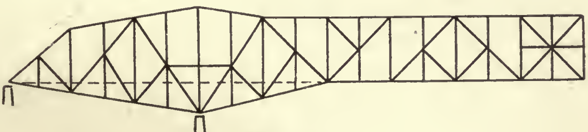


Fig. 158.

1,598 feet. J. W. MacLeod was engineer. The **Red Rock cantilever** (Fig. 158) carries a single line of railway over the Colorado river and connects Arizona and California. The

shore and river arms of the cantilever are each 165 feet in length and the center suspended span 330 feet, making the total length of bridge 990 feet. The clear underneath headroom is 41 feet above high water and the trusses are 25 feet apart on centers. It contains 750 tons of steel and was erected in eighty days, the design and construction being under the direction of J. A. L. Waddell. At the time it was the largest cantilever in the United States. It has recently been strengthened for increased loads by placing under it some additional river piers.

343. The new **Verrugas viaduct** (1890) replaced an old iron trestle of 1872, which had Fink trusses on three double towers, over which the Lima and Oroya Railway crosses the Verrugas valley and river, 52 miles from Callao, Peru. The length is 575 feet, and the deck is 250 feet above water. In the renewal (Fig. 159) the center and highest tower was omitted, and the distance between the side towers spanned

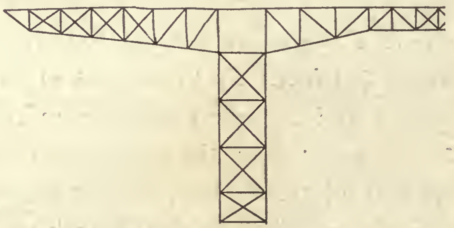


Fig. 159.

with a cantilever. The new bridge has two lines of trusses 17 feet apart, supported on towers 146 and 179 feet high, 265 feet between centers. L. L. Buck, engineer. The **Pecos viaduct** (1891), with forty-eight spans and a length of 2,180 feet, contains a central cantilever (Fig. 160), with 185 feet clear opening, on towers of regular design founded on separate stone piers, with the longest diameter of the pier parallel with the river. The bridge carries a single track on trusses 10 feet

apart, at a height of 320 feet above the water, and was designed by Adolphus Bonzano for a branch of the Southern Pacific, the average cost of the viaduct being $119 per lineal foot. It was strengthened (1910) by adding a center line of trusses and girders supported on new cross girders between the columns. The regular columns were reinforced by the addition of angles and flats to the old zee bar sections, and in the cantilever bents were placed new central uprights. At the West end nineteen spans were removed and the bank supported temporarily on timber, while an embankment was made The reconstruction required 1,100 tons of metal, 80,000 drilled holes and 135,000 field rivets.

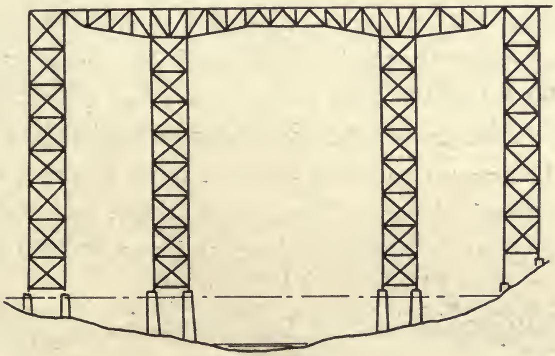


Fig. 160.

344. Three special achievements in cantilever bridge design were completed in Europe in the years 1890-91. The bridge over the Firth of Forth in Scotland, the Neckar at Mannheim, and the Danube at Cernavoda.

As early as 1818, James Anderson of Edinburgh, made plans for a suspension bridge (Fig. 103) to cross the **Firth of Forth** with three spans of 1,500 to 2,000 feet and an estimated cost of $1,000,000, but active work was not begun until 1880, when new designs were made by Sir Thomas Bouch for a stiffened suspension with two spans of 1,600 feet each and an

estimated cost of $10,000,000. On these plans (Fig. 117), a contract for construction was awarded, but the failure of the Tay bridge, designed by him, caused the plans to be abandoned and new ones begun in 1881 by Sir John Fowler and Sir Benjamin Baker, on the cantilever principle. The bridge has three cantilevers, the center one founded on an island, with two spans of 171 feet and a clearance of 152 feet beneath it. The trusses are not parallel, but lie in warped planes 120

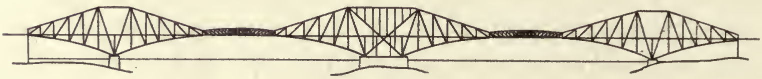


Fig. 161.

feet apart at the piers and 31½ feet at the ends. The arms were at first 615 feet, with suspended spans of 500 feet (Fig. 161), but weie changed to 680 and 350 feet, respectively (Fig. 162). The two end cantilevers stand on piers 155 feet apart logitudinally and the center one on similar piers 270 feet apart. The center tower is 343 feet high, tapering out to 41 feet at the end of arms. The whole bridge, including twenty approach spans, is 8,300 feet long and cost $16,000,000, equal

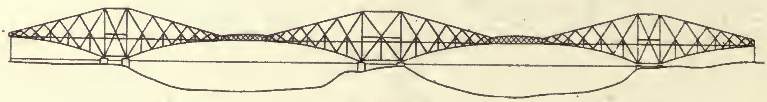


Fig. 162.

to six and one-half cents per pound, or $2,400 per lineal foot. The cantilever part, 5,360 feet long, weighs two tons per foot at the center and thirteen and one-half tons per foot at the piers, or an average of about ten tons per lineal foot of bridge, containing 51,000 tons of steel costing $13,000,000. Most of the compression members are hollow tubes, the largest being 12 feet in diameter and in the light of more recent experience are not the most economical and will probably not be repeated. The bridge carries two lines of rail track over which

trains pass at maximum speed, and the two channels have a maximum water depth of 218 feet. Seven years were occupied in building it and the services of 4,000 to 5,000 workmen were employed at different times. It is said that a bridge across the Forth was proposed in 1740, but no authentic accounts are obtainable of its exact position or the type of bridge considered.

345. Competition for the Frederick bridge over the **Neckar at Mannheim** was invited in 1887, and it evolved four interesting designs, one of which, 620 feet in length, was accepted, and construction completed in 1890. The upper chord follows the line of a suspension, with false members joining the cantilever and suspended spans to complete the continuity.

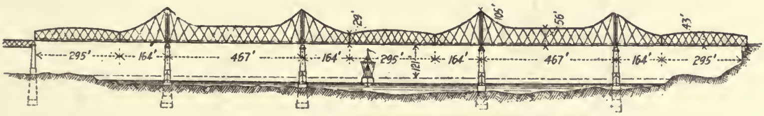


Fig. 163.

It replaced an old suspension bridge of 1845 and is one of the most interesting and artistic cantilevers in Europe. The bridge over the **Danube at Cernavoda, Roumania,** is divided into two parts by an island, the smaller of the two channels being known as the Borcea river. The bridge over the main channel (the Cernavoda bridge) is 2,460 feet long in five spans (Fig. 163), while the Borcea in three spans is 1,380 feet long. The total metal work including both approaches and 4,770 feet of island viaduct is 13,450 feet long, or about two and one-half miles. The floor is 121 feet above high water on the larger bridge and 62 feet on the Borcea. A single line of railway lies between the trusses, which have a batter of 1 in 10. The Cernavoda bridge contains two anchor spans of 467 feet between tower centers with overhanging arms 164 feet long and suspended span of 295 feet, making

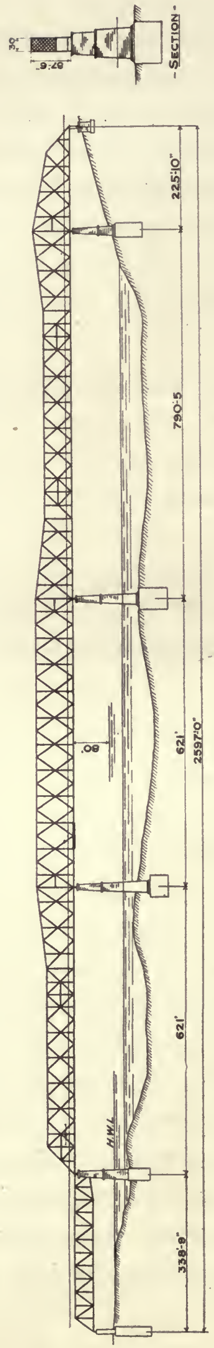


Fig. 165.

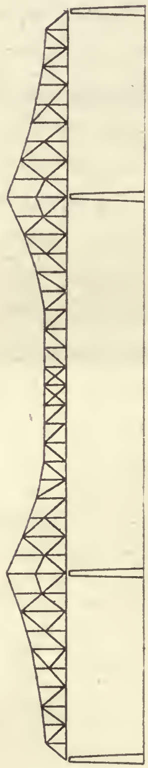


Fig. 164.

the distance between middle piers 623 feet. The length is 2,460 feet, the cost $1,570,000 (or $135 per lineal foot), while the total cost of both bridges and approaches (13,450 feet) is $6,000,000. The larger is quite similar in outline to the Poughkeepsie, Memphis and Thebes bridges in America.

346. Two cantilever highway bridges in the western states, which are worthy of special notice, are at Spokane, Wash., and Roseburgh, Ore. The one at Spokane carries Monroe Street at a height of 140 feet above the Spokane river. It is 1,300 feet in length and was completed in 1892, but is now being replaced by an arch of solid concrete. The Roseburgh bridge over the North Umpqua river is a combination bridge with metal tension bars and timber compression members. The two anchor arms of 147 feet, and 105-foot projecting cantilevers, support an 80-foot suspended span, making a distance of 290 feet between towers and a total length of 584 feet. The trusses are 19½ feet apart on centers with 20-foot panels, and are 40 feet deep over the piers. At the time of its completion this was the only combination cantilever of large proportions.

347. The **Central bridge** (1891) over the Ohio river between Cincinnati and Newport (Fig. 164) accommodates a highway, two sidewalks, and two lines of trolley track on a deck 100 feet above low water at the center. The anchor and cantilever arms are 250 feet and 156 feet long, with 208-foot suspended span, making a clear distance of 520 feet between towers. The two 7-foot walks are outside the trusses, the road 24 feet wide (total width 42 feet), and the length, including fixed spans and viaduct, is 2,966 feet. One of the largest bridges of this type in America was completed in 1892 over the **Mississippi river** at **Memphis, Tenn.** (Fig. 165), from designs by George S. Morrison. He states in his report that his preference was for a symmetrical arrangement, with

three equal spans of 675 feet or, if one span must be longer than the rest, to place the longest one in the center, but the War Department required the longest span at one side. The bridge has a highway and single line of railroad, with clearance beneath it of 110 feet above low water. The approach viaduct is 2,600 feet long, and the central portion is 2,258 feet, with two lines of trusses 30 feet apart and 78 feet deep. This depth of truss is not economical, but was made small to

Fig. 166.

facilitate erection. The continuous span has cantilever arms of 170 feet at each end with suspended spans 450 feet long in the adjoining panels. The weight of steel is 8,160 tons, averaging three and one-half tons per lineal foot, and costing 5.9 cents per pound in place.

348. Cantilever bridges are not ordinarily used in parks, but one of this type in the form of an arch-cantilever was built for a foot bridge in 1894 over the lagoon in Lincoln Park, Chicago (Fig. 166), with a central span of 180 feet

and 99-foot anchor arms. The panels are 18 feet and the floor 20 feet wide, of reinforced concrete, with 3½-inch slabs on 2½x8-inch joist, 1 foot apart on centers. The deck is high enough to leave clearance under it for small sail boats with masts which enter the lagoon from the lake, and the elevated floor with a steep grade is reached at each end by stairs. The bridge was designed by W. L. Stebbings of Chicago, and is ornamental to suit its location.

349. Two highway bridges with outlines which cannot be commended are the ones over the Mississippi river at Winona, Minn. (Fig. 167), and at Davis Ave., Allegheny City, Pa. The **Winona bridge** (1894) is not on the direct line of the highways which it connects, but is several hundred feet west of them near the railroad bridge, and is approached at either end by

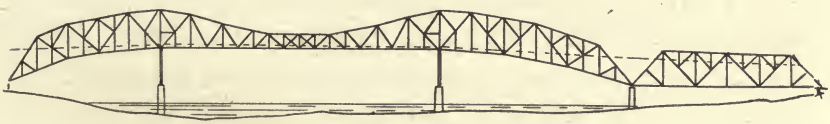


Fig. 167.

viaducts parallel with the river, one of which passes over a very attractive little park on the levee. The width of the river at low water is crossed by a three-span cantilever, and at the north end is a 250-foot fixed span over the high water channel. A center clearance of 75 feet above low water was demanded for navigation, and the floor, which is 23 feet wide, was sloped up to the center on a 4 per cent grade. The top of the stone piers are at high water level, and the two center ones are surmounted with iron towers. At the sides, where underneath clearance is not required, the bridge changes from through to deck construction, and the anchor arms curve downward to the piers, making a more stable connection to them and avoiding the use of extra towers. The suspended span over the channel is connected to the cantilever arms by

false members with sliding joints which completes the continuity of the upper chord. The cantilever portion is 810 feet long, but the whole, including the approach viaduct, has a length of 2,700 feet, and contains 500 tons of metal. It was designed by George T. Baker of Davenport, and built in 1894 by Horace E. Horton at a cost of $100,000. The Davis Ave. cantilever (Fig. 168), referred to above, has two lines of trusses 22 feet apart, with 20-foot panels and a road

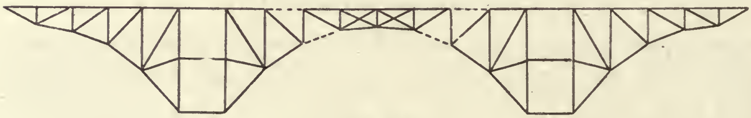


Fig. 168.

36 feet wide, paved with asphalt on buckle plates. It is about 400 feet long with 156-foot center span and cost $26,700.

350. In Paris (1895-96) were built two interesting street bridges, the first, known as the "**Mirabeau Cantilever**" over the Seine, connecting the industrial district of Grenelle-Laval with the residential quarter of Auteuil. The bridge is a very artistic design and is remarkable for the shallow

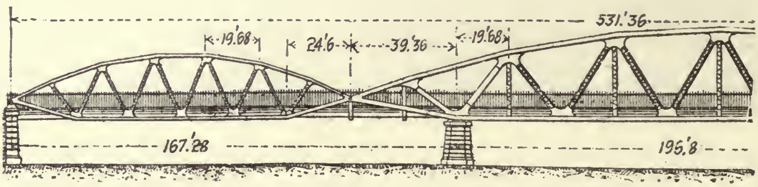


Fig. 169.

depth of the metal ribs, which are 17½ feet over the piers, decreasing to about 3 feet at the center, seven of which are placed about 10 feet apart beneath the roadway. The design was by M. Resal, the center span having provision for arch action and the structure cost $413,000. Tolbiac street bridge (1896) over the station yards of the Orleans Railway, in Paris, has three spans (Fig. 169), the center trusses projecting

39 feet over the piers and supporting the end of the shore spans. Instead of making the chords continuous, the construction is emphasized by omitting chords in the junction panels, showing clearly the cantilever feature. The end and center spans are 167 feet and 197 feet long respectively, with trusses 52 feet apart containing between them a 32-foot road and two sidewalks.

351. Two bridges in South America of unusual interest are those at Cachoeira in Brazil and Honda in Colombia. The former is a heavy street bridge with solid paving on metal trough floors, and was designed by Max Ende of Paris and opened in Sept., 1895. An unusual feature is the two equal anchor and cantilever arms balanced over the piers, with con-

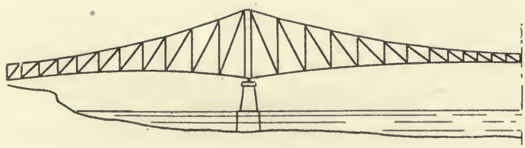


Fig. 170.

tinuous top chords but without a suspended span, and an approach span at each end. The road is 34 feet wide with a 5-foot projecting walk outside of each truss. Piers consist of double cylinders 10 feet in diameter, framed together and filled with concrete, and the whole bridge, which is 524 feet long, contains 722 tons of metal which was exported from England to Brazil and all excepting the center span erected on falsework. The Magdalena river bridge at Honda, Colombia, has a center span of 360 feet with through trusses 17 feet apart, and is proportioned to carry a live load of only 500 pounds per lineal foot.

352. One of the best and most artistic bridges in Europe is the **Franz-Joseph cantilever** (Fig. 170) over the Danube at Budapest. Several very interesting designs were submitted

in 1894, in the competition for this bridge. They provided a clear waterway of 1,000 feet and a deck 52 feet wide, at estimated costs of one to two million dollars. One design has a single cantilever span of 1,000 feet without piers and shore towers 130 feet high, the upper chord following the catenary curve of suspension cables. The design of Aurel Czekelius, which was accepted, has two river piers 175 meters apart supporting cantilevers which project 64 meters over the piers, from the ends of which a center span 46 meters long is suspended. The anchor arms are counterweighted with 600 tons of cast iron at each end. The road is 11½ meters wide with wood block paving, and outside the trusses are foot walks 3 meters wide paved with asphalt. The bridge contains 6,000 tons of iron, including the 1,200 tons of counterweight, and was completed in 1896 at a cost of $950,000. Another, in Hungary, over the Theiss river at Tokaj, contains several new and interesting features. The framing has riveted connections, and the upper suspension members bearing on rocker towers are separate from the stiffening trusses, emphasizing their purpose and making all stresses determinate. The anchor arms are loaded with 81 tons of masonry counterweight below the floor, similar to the bridge at Budapest, except that masonry is used for counterweight instead of iron. The clear width between trusses is 40 feet, the distance between piers, 351 feet, and total length 690 feet, the whole containing 770 tons of iron. The Forsmo bridge is a railroad cantilever with five spans crossing the Angerman river in Sweden, north of the 67th parallel of latitude, within the Arctic Circle. The deck, 133 feet above high water, is supported by trusses on steel towers and granite piers. Two anchor spans at the right and left of the center have projecting arms supporting the ends of the center and shore spans. The center span is 251 feet between pier centers, and the total length of bridge with

approaches is 964 feet. It contains 688 tons of iron, 208 tons of which is in the towers, and the whole bridge including foundations cost $133,000. A bridge somewhat similar to the one at Budapest was completed in 1895 from designs by J. Madison Porter, crossing the **Delaware river at Easton,** Pa., to replace Timothy Palmer's old covered wooden bridge of 1805. It has equal anchor and cantilever arms of 125 feet with a 50-foot suspended span, making the total length 550 feet. The bridge has no upper lateral system excepting at the towers, and the eyebar upper chords are in tension under all conditions. A long bridge at Point Pleasant, N. J., with

Fig. 171.

thirty-three spans, has the truss frame of alternate spans projecting one panel length over the piers, supporting short suspended spans. The bridge has thirty-two fixed spans 44 to 56 feet long, and 137 feet draw (total length, 1,910 feet). The road is 20 feet wide, with a 5-foot walk on one side, with lattice trusses 7 feet deep supporting floor beams on the bottom chord gusset plates. Each pier is composed of two steel cylinders 3 feet in diameter with three piles in each, the space around the piles being filled with concrete. It was com-

pleted in 1897 from designs by D. E. Bradley and the writer.

353. In the years 1892 to 1897 designs appeared for several proposed cantilever bridges, the largest being one over the English Channel (1892), between France and England (Fig. 171), with a length of 21 miles. The plan showed alternate spans 400 and 500 meters long at a height of 60 meters above the surface, supported on double cylinder piers in water 50 to 60 meters deep, the suspended spans being 125 meters long. The two lines of trusses would be 25 meters apart at the piers tapering to 10 meters at the cantilever ends next to the suspended spans, with provision for two tracks, and the design had an estimated weight of 760,000 tons of steel and an estimated cost of $170,000,000. Other interesting designs were those for the proposed bridge over the St. Lawrence at Montreal, the Ohio at Bellaire and the Canadian channel at Detroit. In January, 1895, Walter Shanley of Montreal and Ottawa, consulting engineer for the bridge company, offered prizes and called for competitive designs for a bridge to cross the St. Lawrence, with one cantilever span of 1,250 feet and two side spans of 500 feet, with provision for two steam railroad tracks, two electric railroad tracks, a highway and two foot walks. In response eight cantilever designs were submitted by Messrs. A. L. Bowman, H. E. Mertens, J. Ritchie, Edward S. Shaw, Henry Szlapka, T. K. Thomson, J. Welsh and C. H. Wright, with estimated costs of one and a half to six million dollars. The first and second prizes were awarded to Edward S. Shaw and A. L. Bowman respectively. Mr. Bowman's design had double towers with legs battered 1 in 10 and bottom chords in center and end spans curved for better appearance. The designs of Messrs. Ritchie, Welsh and Wright also had double towers, but the truss depth used by Mr. Welsh was too small for economy or appearance. Mr.

Shaw's design had four lines of trusses in vertical planes with 25-foot panels, a deck 80 feet wide, and outer trusses 70 feet apart, with curved bottom chords and steel towers 230 feet high on granite piers. Grades of two and four per cent respectively were used for the steam and electric railways, and the upper chords on the cantilever arms were approximately catenary curves. Mr. Szlapka's design was shorter than the length specified, with width of only 44 feet between trusses, equal to 1/27 of the span, and had, therefore, a lower cost. The estimated costs for the several designs are as follows:

A. L. Bowman	$3,436,000	Henry Szlapka	$1,500,000
H. E. Mertens	3,200,000	T. K. Thomson	3,140,000
J. Ritchie	6,250,000	J. Welsh	5,632,000
Edward S. Shaw	3,514,000	C. H. Wright	1,900,000

354. In the early part of 1897 several designs appeared for a proposed cantilever bridge over the Canadian channel of the Detroit river with a central span of 1,100 to 1,300 feet, and a clear height of 120 to 140 feet above the water. In the same year a design appeared for a highway bridge over the Ohio river at Bellaire, with provision for electric car tracks, central span of 825 feet, and two lines of trusses 40 feet apart. Three years later Mr. Boller prepared plans for the proposed Hell Gate cantilever carrying two tracks of the New York Connecting Railway over the East River, with a central span of 800 feet on steel towers. In addition to the cantilever, his design shows about three miles of approach viaduct.

355. Two highway bridges over the Connecticut river at **Northfield, Mass.,** were completed 1899 and 1904 from designs by Edward S. Shaw of Boston. The first (Fig. 172) has center and side spans of 360 and 108 feet respectively, with trusses in the center span continuous over the piers, and slip joints in the shore spans at the fourth panel point from the abutments. The shore spans were erected on false work and

loaded down with sand, forming anchor arms for the center span which was built out without centering over 30 feet of water. To assist in the erection, temporary timber towers were placed over the piers with guy ropes on either side. The trusses are 22 feet apart and 45 feet deep at the middle, with 18-foot panels and curved top chords, and the whole

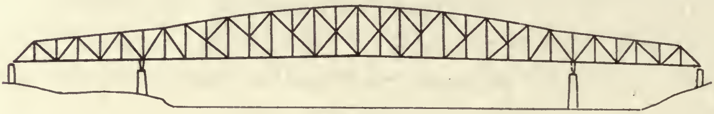


Fig. 172.

bridge contains 280 tons of steel. The other bridge at Northfield is a memorial erected by Francis Robert Schell in memory of his father and mother, bearing bronze tablets on the piers with inscriptions (Fig. 173). As water under the bridge was 25 to 30 feet deep, a form was selected that would act as cantilever during erection. The length of the shore span at the East end was fixed by natural conditions at 80 feet, and for sym-

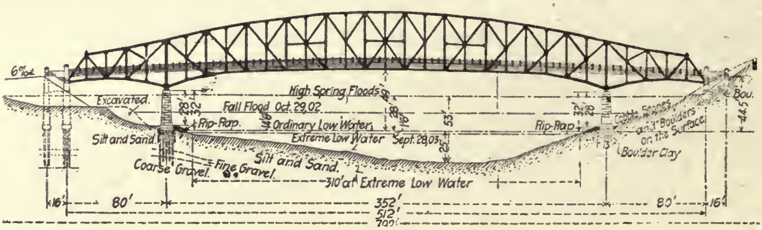


Fig. 173.

metry the West span was made the same, leaving a remaining distance of 352 feet between piers. The trusses are continuous and dead load is at all times transferred to the central piers, with reactions on the abutments from moving loads only. A rope tramway between temporary towers was used for handling and placing the parts in position. Another bridge for which Mr. Shaw prepared an alternate plan crosses the Snake river between Lewiston, Idaho, and Concord, Wash-

ington. The method of securing the required clearance of 70 feet above low water is similar to that used on the Winona bridge (1894) by changing from deck to through construction over the channel, and sloping the anchor arms down to the side piers. The cantilevers stand on rocker bents with anchor arms 238 feet long, which have sufficient dead load in themselves to balance the 119 feet cantilever arm and the 136-foot suspended span, without depending on pier anchorage. The channel span is 374 feet between towers with trusses 22 feet apart on centers. Mr. Shaw's plan had curved bottom chords on the approach spans, giving a better appearance. The bridge is for highway travel only and has a total length of 1,485 feet.

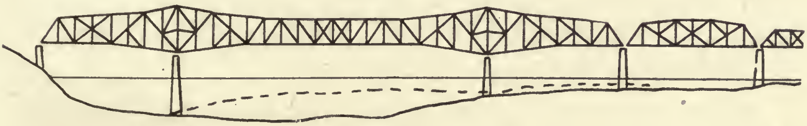


Fig. 174.

356. In the years 1899 and 1900 two notable bridges were erected in Canada at Cornwall and Ottawa. The South channel of the **St. Lawrence river at Cornwall** Island is crossed by a series of simple fixed spans, but the North channel has a cantilever bridge 843 feet long with main piers 420 feet apart on centers, and a draw span over the canal. It has provision for one railroad track with trusses 20 feet apart, and is proportioned for a train load of 3,500 pounds per lineal foot. While being erected by the Phoenix Bridge Co., two of the fixed spans over the South channel fell (Sept. 1898), killing thirty people, but the spans were rebuilt and the bridge opened in 1899. The bridge over the **Ottawa river at Ottawa** (Fig. 174) has a cantilever span due to a collection of logs and sawdust from neighboring saw mills which is 50 to 60 feet deep on the river bottom. It was found impractica-

ble to sink piers through this bed of timber and sawdust, and the channel was therefore spanned with a cantilever on piers 555 feet apart, with an under clearance of 45 feet. The trusses are vertical and 24 feet apart, with a single steam railroad track and two walks between them, and highways 21 feet wide with electric railway tracks on outside cantilever brackets, making the deck 66 feet wide. The central bridge is 1,053 feet long, but the whole including two fixed spans and viaduct has a length of 2,286 feet between abutments. The cantilevers are 90 feet deep above the piers, with 247-foot anchor arms, and suspended span is 308 feet long, between the 123½-foot projecting arms. It crosses the river at Nepean Point near the parliament buildings, and was named the Royal Alexandria Bridge in honor of the English queen. It was designed by G. H. Duggan, chief engineer of the Dominion Bridge Co., of Montreal.

357. The Kaisersteg foot bridge over the river Spree, near Berlin, is a three span cantilever 282 feet long between center towers, with four equal arms of 141 feet and center hinge, but without a suspended span. It has a clear height above water of 32 feet and a floor rise of 5 feet between the piers. The center span is stiffened with arch ribs overhead, connected with lateral bracing, thus avoiding the use of long diagonal members in the trusses near the towers. The four cantilever arms were floated into position and connected, and the arches placed afterwards. The towers and portals are ornamented and the complete bridge cost $27,600.

358. The **Highland Park bridge** (Fig. 175), crossing the Allegheny river from Pittsburg to Sharpsburg, resembles somewhat the Francis Joseph bridge at Budapest. The distance between towers is 450 feet, divided into three equal parts of 150 feet, while the shore or anchor arms are each 200 feet. The two trusses are 24 feet apart with space for a highway,

two car tracks, and two foot walks with an outside width of 36 feet and a total length of 1,850 feet. The 850-foot cantilever has 700 tons of steel, while the whole bridge contains 1,250 tons, costing with substructure $175,000. Herman Laub was engineer. Another over the Allegheny between Reno and Oil City, finished 1902, has a central span of 413 feet. The Boston

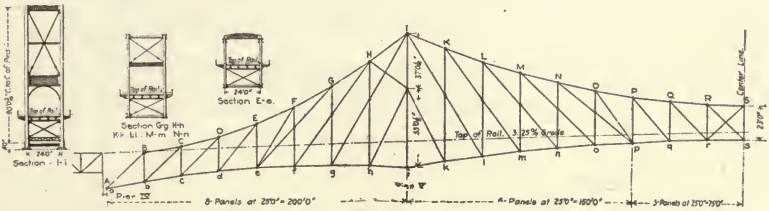


Fig. 175.

highway bridge over the Youghiogheny river near McKeesport for the Versailles Traction Co was raised 24 feet at one end, under the direction of Herman Laub, at a cost of $20,000, to provide under clearance for another road.

359. A three span bridge (Fig. 176) of unusual form was placed across Tygart's river near Fairmount, West Vir-

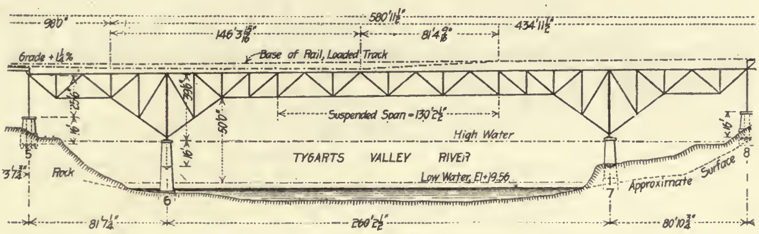


Fig. 176.

ginia, with a center span of 260 feet, between piers one-half of which with eight panels, is suspended. The two lines of trusses are 18 feet apart with riveted joints, and the steel towers stand on masonry piers with their tops at high water level. The bridge has an under clearance of 50 feet and was designed by Charles Worthington, engineer.

360. A suspension cantilever (Fig. 177), which is similar to a form proposed in America in 1869 and to a design submitted in 1895 for the Danube river bridge at Budapest, was erected in 1901 at Long Lake, Hamilton County, N. Y., with a single span of 525 feet. The central portion of 175 feet is suspended between cantilever arms of the same length, and two lines of trusses standing in vertical planes are 24 feet

Fig. 177.

apart at the ends, tapering to 16 feet at the center span, an arrangement which adds greatly to the lateral stiffness. It contained 220 tons of steel, the erection of which cost $15 per ton and was designed by C. S. Mallory, engineer.

361. The second largest cantilever bridge in Great Britain is at **Connel Ferry,** Scotland, over Loch Etive (Fig 178). The design was made by Sir John Wolfe Barry, and the bridge

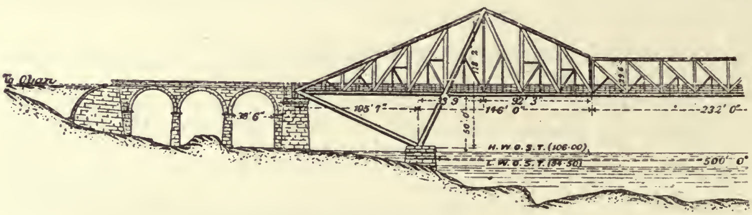


Fig. 178.

manufactured and erected in 1903 by William Arrol and Co. The channel is 690 feet wide and very deep at the center with a current of twelve miles per hour, making it impracticable to use a center pier, but two were placed in shallow water at the sides, 524 feet apart. The approach at each end contains three masonry arches with spans of 38½ feet ending with curved wing walls. The bridge has a single line of rail track

and contains 2,600 tons of steel. A notable feature of the design is the triangular anchor arms with sloping and battered towers.

362. Four of the largest and heaviest cantilever bridges in America were built in the years 1903 to 1905, at Marietta, Pittsburg, Mingo Junction and Thebes. The **Marietta highway cantilever** (Fig. 179), over the Ohio river, with a 650-foot opening, was finished in 1903 from designs by C. L. Strobel. The lack of symmetry is said to be due to the necessity for two channel spans and a pier in the shallow part of the river. The north and south anchor arms are 130 feet and 600 feet, with two lines of pin connected trusses 28 feet apart, the whole length including two simple spans and 640 feet of viaduct, being 2,460 feet. It is proportioned for 30-ton electric cars and a steam roller. The 650-foot portion contains 755 tons of steel, of which 220 tons is in the suspended span, and the 600-foot anchor span has 1,000 tons of steel, the whole with viaduct approach containing 2,400 tons, and costing $800,000. The Wabash Railroad Company in 1904 built two very similar double track bridges over the Ohio river, from designs by Boller and Hodge. The one at Pittsburg (Fig. 180) has a center span of 812 feet, and a length, with approaches, of 1,404 feet, with shore arms 346 feet and towers 126 feet high. The suspended span is 360 feet between cantilevers and 60 feet deep, with trusses 32 feet apart and 30 and 40-foot panels. The bridge contains about 7,000 tons of steel, which is equal to 9,300 pounds per lineal foot. It has a clear height of 70 feet above the river, and was completed at a cost of $800,000, equal to $533 per foot of bridge. The bridge at **Mingo Junction, Ohio,** like the one previously described, has a 700-foot center span and 298-foot anchor arms, and a total length with approaches of 1,296 feet. The towers are 109 feet high, and the suspended span 51 feet deep. It contains 6,000 tons of

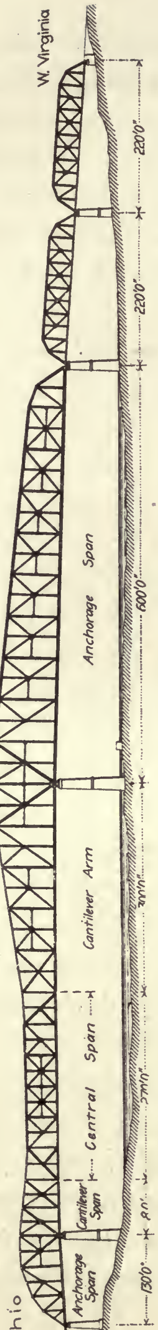


Fig. 179.

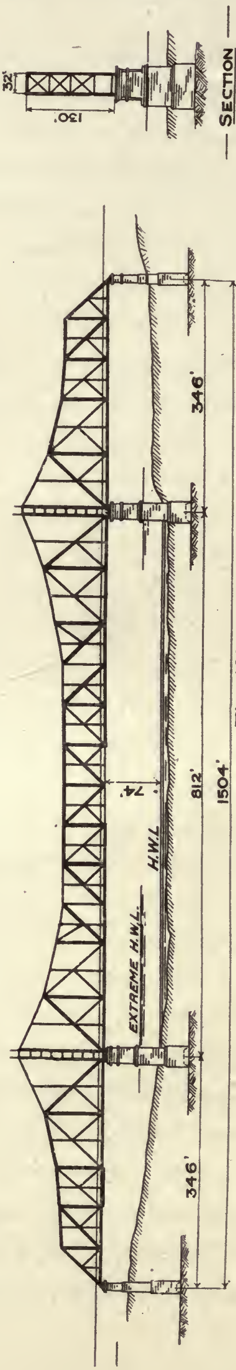


Fig. 180.

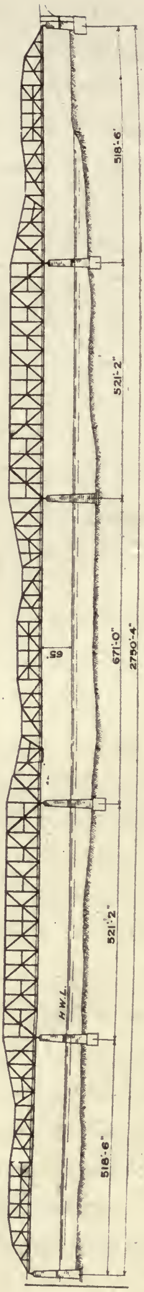


Fig. 182.

steel and cost, with the substructure, \$750,000, equal to \$577 per lineal foot, of which \$200,000 was the cost of four main piers. The bridge over the **Mississippi river** between **Thebes, Ill.,** and Grey's Point, Mo. (Fig. 182), has five spans arranged symmetrically about the center, and a total length of 2,750 feet without the approaches. The distance between center piers is 671 feet and the two adjacent anchor spans are each 521 feet, with cantilevers overhanging the piers 152½ feet, supporting three suspended spans of 366 feet. The two lines of trusses are 32 feet apart on centers, for double track. The superstructure contains 12,000 tons of steel, or about five tons per lineal foot, and cost \$1,400,000, which is equal to 5¼ cents per pound. The substructure cost \$600,000, the total cost being equivalent to \$800 per lineal foot. The water beneath the bridge is 20 feet deep and the concrete piers, which are faced with stone, have an average height of 115 feet. The 1,200 feet of concrete viaduct, 100 feet high, cost \$300,000, or \$250 per lineal foot. The trusses are pin connected, with panels 30½ feet long. The free span and cantilever arms weigh 11,600 pounds per lineal foot, and the suspended span 7,800 pounds per foot. The small truss depth above the piers was selected to permit the use of overhead travelers and facilitate erection. The bridge was completed in 1905 from designs by and under the direction of Messrs. Alfred Noble and Ralph Modjeski, engineers. Other smaller bridges in America are at Moline, Ill., and Croton Lake, N. Y. **The Moline highway bridge** (Fig. 183), over Rock river, is a three span cantilever with a simple span at one end. The new bridge was placed on the piers of an old combination wooden bridge and the river interests required a clearance in the center of at least 35 feet. These conditions, with the small appropriation of \$25,000 for construction, account for the design. The trusses are riveted and 19½ feet apart on centers, with anchor spans fastened

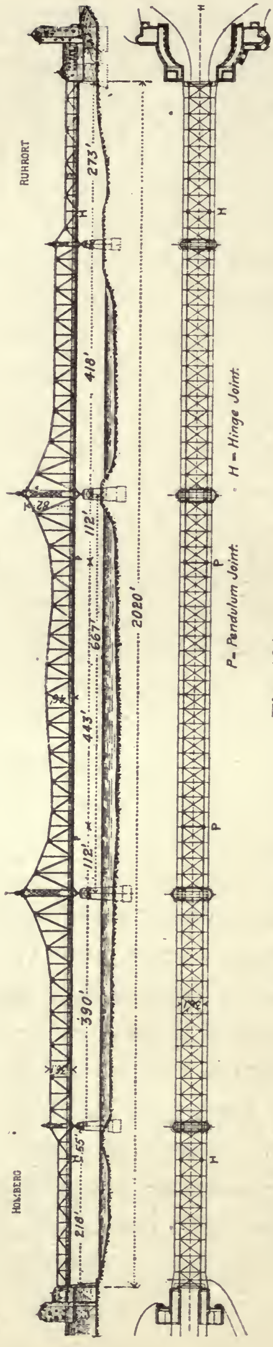


Fig. 184.

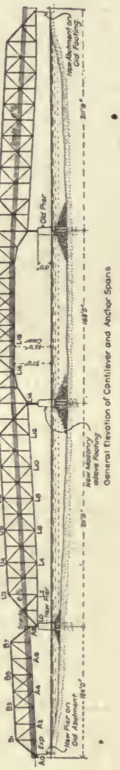


Fig. 183.

at the shore end and standing on rocker bents over the river piers. All spans excepting the center one were erected on false work. The floor rises on a 6 per cent grade with truss chords parallel to the floor, excepting the four lower panels of each anchor span adjoining shore, which are raised nearer to the horizontal to clear high water. It was designed by F. C. Moore of Milwaukee, Wis. The Pines bridge, over a part of Croton Lake, has center and side spans of 384 and 160 feet, respectively, with two lines of trusses 22 feet apart and 51 feet deep at the center, and a plank floor on steel joist. The suspended span is 160 feet long and 24 feet deep, and the whole bridge, though a cantilever, was erected on false work. The top chord is curved somewhat like that at Clinton, Iowa, in the effort to give it a more pleasing appearance.

363. Two cantilevers in France of this decade are those at Villefranche, over the Saone (1904), which replaced an old suspension bridge with a single span of 528 feet, and the Passy viaduct, over the Seine (1906). The Villefranche bridge

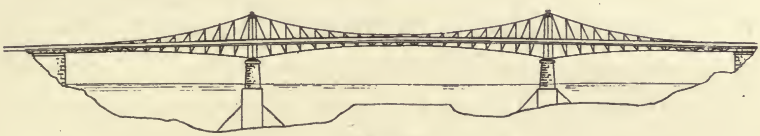


Fig. 181.

(Fig. 181) is unusual in having no suspended span, the cantilever arms meeting at the center with sliding joints. The end and center spans are 150 and 220 feet, making the whole bridge 520 feet in length. The bottom chord of the center span is the segment of a circle with 5-foot rise, and the chords of side spans are curved to correspond. The trusses have a depth of 32 feet over the piers and 9 feet at the center, with a 23-foot road and 10-foot cantilever walks outside. It contains 740 tons of steel and was finished in 1904 at a cost of $110,-500. The Passy viaduct crosses two arms of the Seine at an

island, and carries street travel on the main deck, and two tracks of the Metropolitan Railway of Paris on a center elevated viaduct. Each bridge is a three span cantilever, with total lengths of 288 and 367 feet, respectively.

364. The new bridge between **Homberg and Ruhrort** (Fig. 184) is the largest of its kind in Germany, and crosses two canals and a harbor basin in addition to the river Rhine. It contains five spans with lengths of 296, 405, 678, 427 and 279 feet, with a total length of 2,085 feet, and is not symmetrical with reference to span lengths. The road is nearly level, with a 38-foot carriageway, two lines of electric car track, and two 8-foot walks, making an outside width of 54 feet. In the center opening, 667 feet long, the suspended span of 450 feet hangs freely between the 114-foot cantilever arms. The super-

Fig. 185.

structure cost $445,000 and the substructure $315,000, or a total, with approaches, of $1,092,000. The central spans are paved with wood, and the end ones with stone. Other interesting bridges in Europe are those across the Mattig river, Austria, the Weser in Hameln, the Wiedendammer bridge in Berlin, Tunxdorf over the Ems (Fig. 186), a bridge over the Tanaro, and one over the Main át Frankfort. The Mattig

Fig. 186.

bridge is unusual in having short girder extension arms at either end of the central 100-foot truss span. The Weser in Hameln (Fig. 185) has a distance between piers of 150 feet without suspended span, curved top chord similar to a sus-

pension, and anchor arms at either side 47½ feet long, with straight top chords. The stiffened suspension footbridge over the **Main at Frankfort,** designed by Schnirch in 1869, has anchor arms one-half the length of the center span, with trusses standing vertical and 15 feet apart, and a total length of 550 feet, and has part cantilever action. The deck is approached at either end by a series of steps.

365. A design was prepared for the proposed bridge across the **St. Lawrence river at Quebec,** 1885, by T. Claxton Fidler and Sir James Brunless, with a clear distance of 1,440 feet between towers and 1,550 feet on centers. The top chords were curved, and the depth at towers was 258 feet (Fig. 187). The design showed four lines of trusses in pairs, or two separate bridges braced together, 90 feet apart on centers,

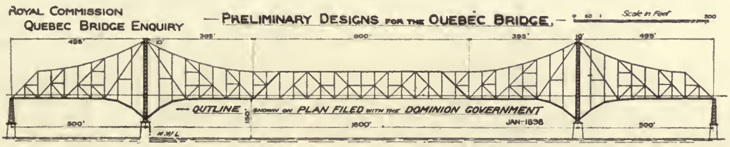


Fig. 188.

with extreme width of 108 feet. Each approach had six 40-foot masonry arches with deck 150 feet above the river, which is 180 feet deep in the middle. Twelve years later Edward S. Shaw of Boston prepared a design with towers 1,440 feet apart on centers and general features similar to his design for the proposed bridge at Montreal, submitted in the same year (1897). The anchor spans on his design were 560 feet, with 320-foot simple spans at each end. The cantilevers were 300 feet deep over the piers, and the outside width 90 feet, with an estimated cost of $3,000,000 to $4,000,000. Other proposed designs are shown in the Figs. 188, 189 and 190. In 1900 a contract was awarded to the Phoenix Bridge Co., on their own design (Fig. 189), for a bridge 67 feet wide, with

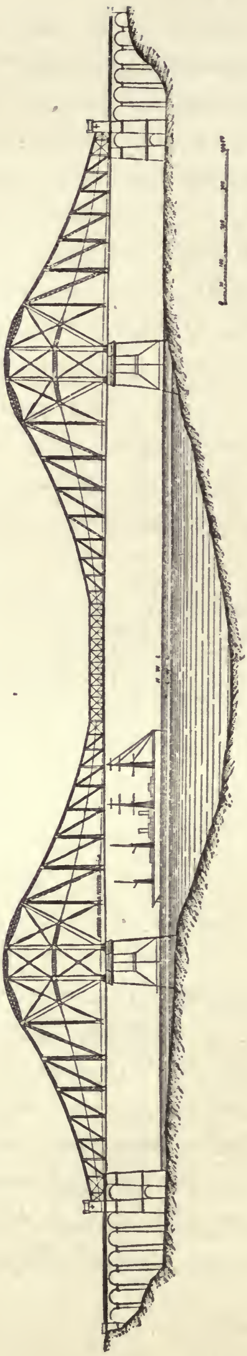


Fig. 187.

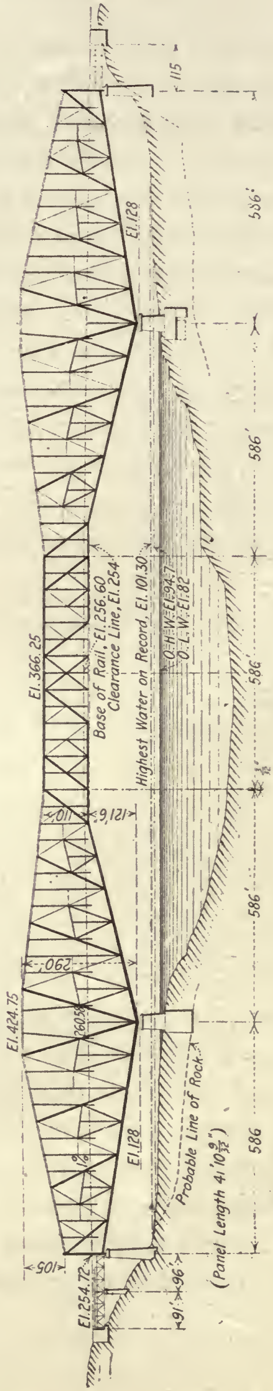


Fig. 191.

center piers 1,800 feet apart, a 675-foot suspended span 120 feet deep, and 500-foot anchor arms, and a total length of 3,300 feet, containing approximately 13 tons of steel per lineal foot, at a proposed cost of 6.6 cents per pound. The trusses were 315 feet deep above the towers, with 50 and 56-foot panels in the anchor and cantilever spans, respectively. When one cantilever was nearing completion, the bridge fell on the

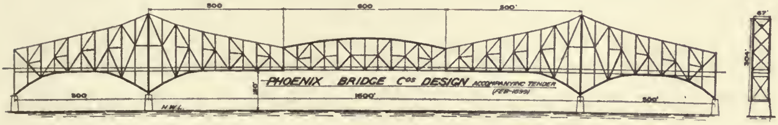


Fig. 189.

29th of August, 1907, because of the crippling of bottom chords near the piers, killing eighty workmen and causing a loss of 20,000 tons of metal. Investigation of the cause of its collapse was made by a commission appointed by the Canadian Government, headed by Professor John Galbraith of Toronto University, and in 1909 the project was taken over by the Dominion Parliament and a board of engineers appointed to prepare designs and superintend its construction. The de-

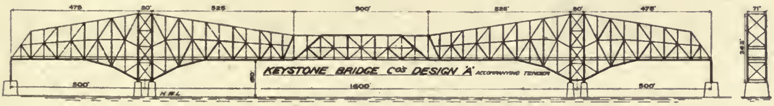


Fig. 190.

sign proposed by the board (Fig. 191) showed a central span of 1,758 feet, necessitating moving one of the main piers about 50 feet out into the river. Trusses are 88 feet apart, and the estimated weight of metal is 65,000 tons, as compared to 35,000 tons in the bridge that failed. Another proposed long span cantilever bridge in America is that over the Mississippi river at New Orleans, with a center span of 1,066 feet and

440-foot suspended span. The plans made in 1906 showed 606-foot anchor arms with trusses 40 feet on centers and 72 to 160 feet deep, and floor 105 feet above low water, which has a maximum rise of 20 feet. It was proposed to grade the approaches 1½ in 100, using seventy-four alternate spans of 60

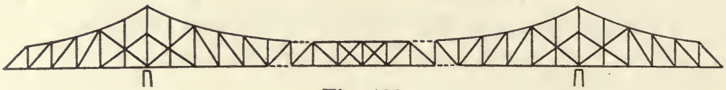


Fig. 192.

and 120 feet, and a total length, including the cantilever, of 10,630 feet. The estimated weight of steel was 11,850 tons, and cost $6,000,000. A design and tender was prepared and submitted by the writer in February, 1905, for a cantilever bridge (Fig. 192) 500 feet long over the Elk river at Charles-

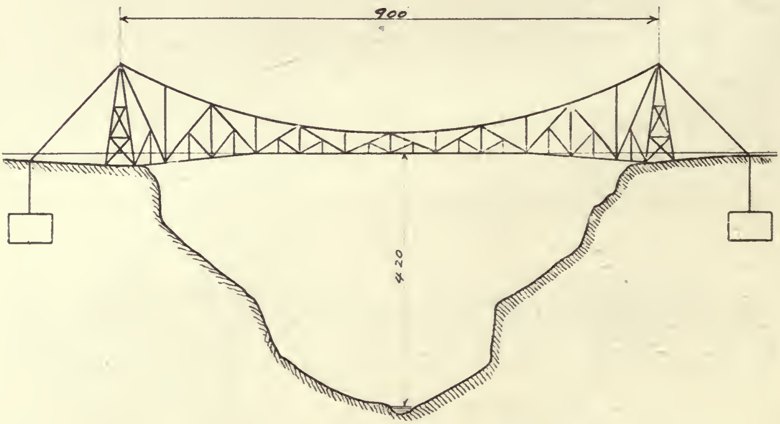


Fig. 193.

ton, West Virginia, with curved top chord, to replace the old suspension, which collapsed a few months before. In the following year several outline designs (Figs. 193, 194 and 195) were made by H. G. Tyrrell, for cantilever bridges to cross mountain gorges in western America, one of the gorges having a depth of 420 feet.

366. The Blackwell's Island (Fig. 196) or **Queensboro bridge** (1901-09) is a continuous cantilever with unequal channel spans of 1,182 and 984 feet at either side of the island anchor span of 630 feet, and shore arms of 469 and 459 feet.

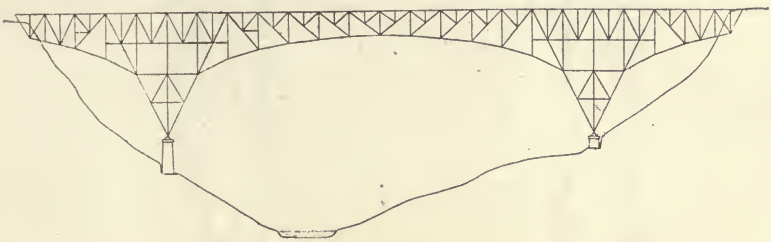


Fig. 194.

The channel openings are connected at the center without suspended span, thus making the stresses indeterminate. Two lines of vertical and parallel trusses 60 feet apart on centers support on the lower deck a center carriage way with two

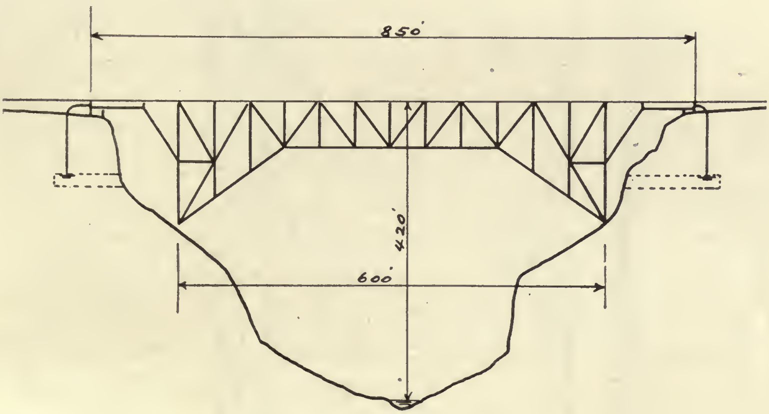


Fig. 195.

car tracks on each side, the outer track being on a cantilever extension of the floor beams outside the trusses, making the deck 86 feet wide. The upper platform has provision for four elevated railroad tracks between the trusses, with a canti-

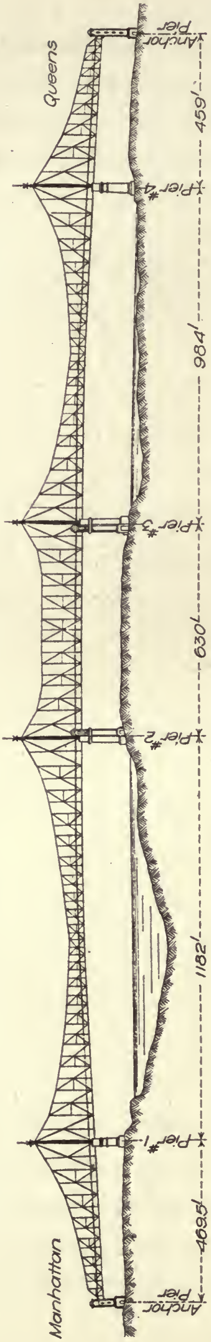


Fig. 196.

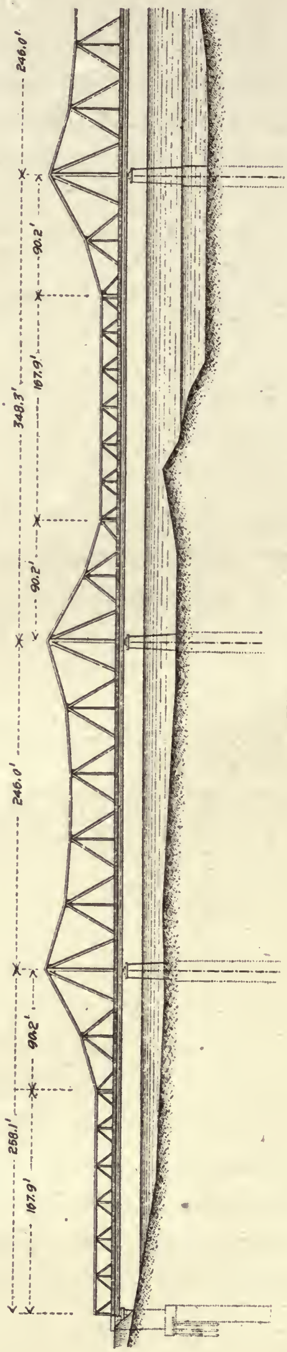


Fig. 199.

lever prominade at each side. It is the first instance in which nickel steel has been extensively used for tension members and pins, and it contains approximately 13½ tons of steel per lineal foot, costing 5.5 cents per pound in place. It was designed by the bridge department of the city of New York, contains the longest cantilever span in America, and is proportioned for heavier loads than any other bridge.

367. Two cantilevers of original design by European engineers appeared in 1908 over the Indus river at Khushalgarh, India (Fig. 197), and at Westerburg over the Hoelzbach, Prussia. The first was designed by Rendel and Robertson, to cross the Indus where it is 175 feet deep. An approach span

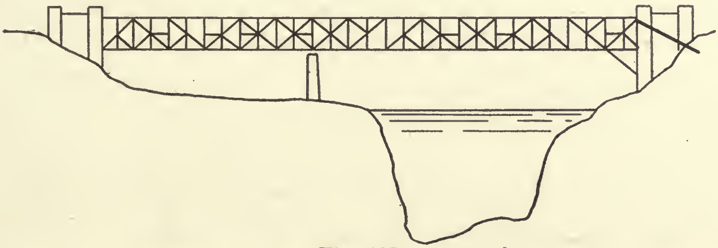


Fig. 197.

with projecting arm forms the cantilever at one end, while at the other end a bracket is supported on the abutment and anchored back into it. It replaced a pontoon bridge and has a railroad track on the upper deck and a highway between the trusses on solid trough floor. The Westerburg bridge (Fig. 198), on the Prussian State Railway, is a five span cantilever viaduct on rocker bents, with 110-foot suspended spans in the second and fourth openings.

368. The **Daumer bridge** (Fig. 199) on the Yunnan railroad system over the Red River in China, completed 1909, has nineteen spans and a total length of 5,544 feet. Nine anchor spans 246 feet between piers have overhanging 90-foot arms supporting the eight intermediate and two end spans

of 168 feet. The anchor spans are 56 feet deep over the piers, tapering to 20 feet deep at the cantilever ends. Trusses are vertical and about 16 feet apart on centers for single track railroad, with a 5-foot walk outside each truss, making a total width of 26½ feet. The bridge contains 5,700 tons of steel and 2,225,000 cubic feet of masonry. Another interesting one was built during the last decade by Sir William Arrol and

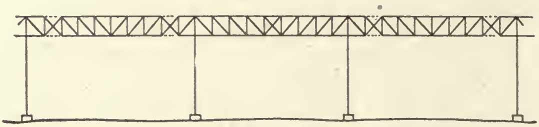


Fig. 198.

Company, crossing the river Nile in Egypt between Ghizeh and Rodah Island, with a total length of 1,755 feet. It contains ten spans of 140 feet, two of 70 feet, and a 220-foot draw. The total width is 66 feet, with asphalt floor on concrete and buckle plates, and accommodation for two lines of electric railway, the foot walks being on extension brackets. For the sake of better appearance the bottom chords are

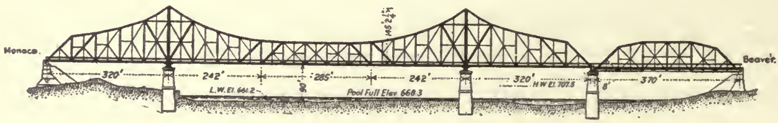


Fig. 200.

curved, and the trusses are continuous over the piers, being cut at the points of contraflexure in alternate spans, the design being similar in this respect to the 1,500-foot viaduct in Algoma designed by the writer in 1901.

369. The latest cantilever bridge in America is one for the Pittsburg and Lake Erie Railroad over the **Ohio river at Beaver,** Pa. (Fig. 200), with a length between center piers of 769 feet, and 320-foot anchor arms, or 1,409 feet extreme, not including the 370-foot fixed span at the Beaver end.

The clearance under is 90 feet and towers have a height of 145 or 235 feet above low water. Trusses are 34½ feet apart for double track, and the bridge was designed by Mr. A. R. Raymer, engineer for the railroad company. Another one is proposed over the Straits of Canso, between Port Hastings and Cape Porcupine, Nova Scotia, Canada, with a central span

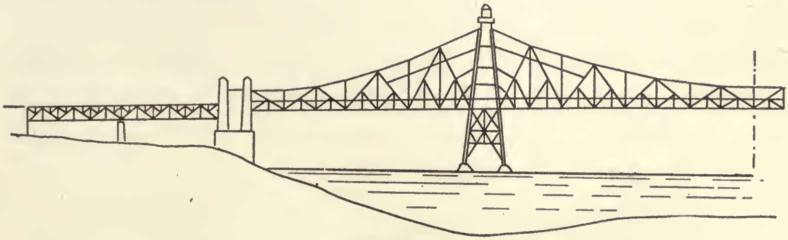


Fig. 201.

of 1,000 to 1,800 feet, while other large proposed ones of the same type in Europe are at Kent, England, and Jutland, Denmark.

370. The bridging of the channel at Sydney, Australia, has been seriously considered since 1880, a design prepared by Pollitzer in one of the early competitions resembling the

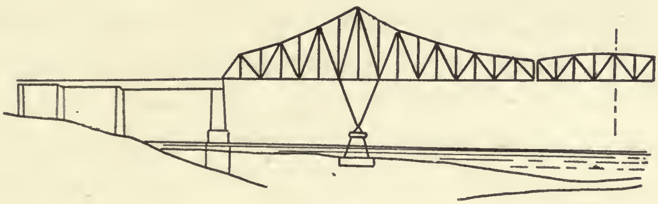


Fig. 202.

Forth bridge. Competitive plans were again invited in 1904, at which time twenty different designs were received, ranging in price from eight to fifteen million dollars, one (Fig. 201) by A. Rieppel of Germany receiving the first prize. It showed a center cantilever span 1,350 feet between towers, with anchor arms of 500 and 580 feet, and trusses battered 1

in 8, with two approach spans at each end. It had a clearance of 180 feet below, with an estimated cost, including approaches, of $10,000,000. The second prize design (Fig. 202) was submitted by Sir William Arrol and Company, and a third received special mention. But the largest projected cantilever bridge is that over the **Hudson river at New York City.** Comparative designs were made in 1894-98 for spans of 2,000 and 3,100 feet in length, showing the relative cost, including both superstructure and foundations to be $27,000,000 and $51,-000,000, the estimate for the 2,000-foot bridge containing 1,780

Fig. 203.

feet of trestle approach to make its whole length the same as the 3,100-foot span. The shorter design (Fig. 203) had a distance of 2,300 feet between tower centers, which were 534 feet high, with truss web members arranged to transfer loads in the shortest and most direct course to the points of support. The conclusion from the comparisons was that cantilevers are economical for highway bridges in spans up to 1,400 or 1,600 feet, and for railroad bridges up to 2,000 feet. Of the seventy-seven bridges herewith described, seven were built prior to 1880, eighteen between 1880 and 1890, twenty-nine between 1890 and and 1900, and twenty-three since 1900, with about equal numbers for railroad and highway use.

CHAPTER XIV.

WROUGHT IRON AND STEEL ARCHES.

371. The first appearance of a wrought iron arch design was in France in 1779, three years after the completion of the first cast iron arch at Coalbrookdale, England (Fig. 74). It was made by M. Califfe with the unprecedented span of 656 feet, and in 1782 another French engineer proposed a bridge with two spans of 213½ feet to cross the Seine. The next record is in 1796, when James Jordan secured a patent for a so-called suspension bridge which was really an arch with suspended floor, the arch thrust being resisted by ties at the floor level. But the first wrought iron arch actually built was a foot bridge over the river Crou at St. Denis, in 1808, from a design by the French engineer Bruyere. It was a braced arch with straight upper chord and crossed diagonals, and had a clear span of only 39 feet. The new material did not meet with great favor, for cast iron continued in almost exclusive use until the middle of the nineteenth century, and it was not until 1853 that the next wrought iron arch was started, for the Swiss Central Railroad, to cross the river Aare at Olten. It was designed by Etzel and Riggenbach with three plate girder deck arches of 103 feet, and a roadway supported on spandrel columns. In the same year appeared Pont d'Arcole with a single span of 262 feet, designed by M. Oudry. Each span had twelve plate girder ribs with cast iron spandrel-braces beneath the floor. The first use of hinges in a wrought iron arch was for a bridge over the St. Denis canal on the Paris-Aire Railway (1854), with one span of 148 feet. The Theiss river bridge at Szegedin, Hungary, with eight spans of

139 feet, was completed in 1858, and the railroad bridge over the Rhine at Cologne, by Hartwich, was finished a year later. Pont d' Arcole, which had a small rise of only 6.16 meters, was strengthened by anchoring the top chords back into the masonry to produce combined arch and cantilever action, but the anchors all snapped at once, causing partial failure. It was again repaired and in 1888, was still in use.

372. England has few very large metal arch bridges but many smaller and artistic ones. The original Victoria bridge at Pimlico (1860) near the Chelsea suspension, was designed by Sir John Fowler with four segmental deck arches and was widened in 1866 by Sir Charles Fox, to 132 feet between parapets, and until recently was the widest of all bridges. It

Fig. 204.

was originally only 30 feet between parapets, for two lines of railway with three ribs in each span, but the additional width of 98 feet required eight ribs more. The only other important bridge of the kind and time in England was the Westminster bridge over the Thames at London, designed by Thomas Page, 1861, with seven spans from 95 to 120 feet. This was an unusual combination of materials, for the central 52 feet of each rib was wrought iron, while the remainder was cast iron.

373. The three-span deck arch bridge over the Rhine at **Constance-Baden,** designed by Gerwig, 1862, has solid plate ribs without hinges, the upper chord in the spandrels being in three straight lines instead of a curve parallel with the intrados. A somewhat similar one crosses the Ruhr at Dussern (Fig. 204), and they have also been used for arches

in America, but the contrast of intrados curve and straight mitred chord in the spandrels is not satisfactory. The Constance bridge had provision for both railroad and highway travel with artificial adjustment for changes of temperature, and was followed two years later by a plate girder three-hinged arch over the Wien river in Germany, designed by Hermann. The three-span **Coblenz bridge** of 1864, the Rheinhausen bridge of 1873 and the two-span Coblenz bridge of 1879 are similar railroad bridges with square end towers. The first Coblenz bridge (Fig. 205) has often been described and has served as a pattern for many later ones. Each of its three

Fig. 205.

spans has end hinges, used only during erection and afterwards made square ended. It was the first braced arch with parallel curved chords and end hinges, and is probably the most important and best known of all the early wrought iron arches. The ribs have segmental flanges with open lattice,

Fig. 206.

and the deck carries a double line of railway. The Muhlheim bridge over the Ruhr (1865), also designed by Hartwich, consists of three river spans and seven smaller ones, with four-braced parabolic open-web ribs in each span for double track. In the following two years appeared a foot bridge (Fig. 206) over the Bollatfall at Hohenschwangan, by Gerber, a

railroad bridge over the Neckar at Jaxtfeld, by Becker, and a highway bridge over the St. Denis canal at Villette.

374. The Albert bridge over the **Clyde at Glasgow** (1870), designed by Bell and Miller, engineers, had arch ribs 3 feet deep at the center and 4 feet at the springs. It replaced Robert Stephenson's old Hutcheson stone bridge of 1829, the site of which was first occupied by Peter Nicholson's timber arch foot bridge (1803), which had the large span of 340 feet and was only 7 feet wide. The modern iron bridge with its three-

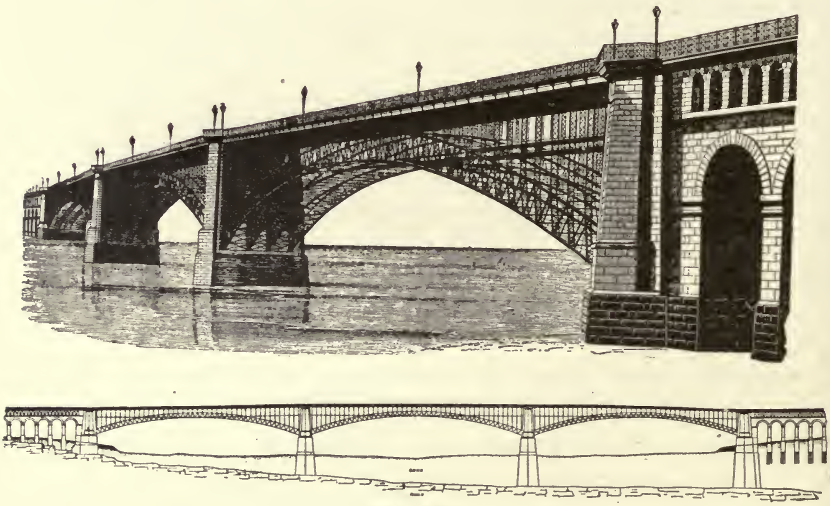


Fig. 207.

deck arches and stone piers on cast iron cylinders, cost $240,-000. In each span are eight wrought iron riveted plate girder arch ribs, the outer ones being ornamented with cast iron facings.

375. The **St. Louis bridge** over the Mississippi river (Fig. 207) is the first steel arch and the first and largest railroad arch in America. Its construction was started in 1869 and continued to completion in 1874. The center span has a clear length of 520 feet and the two side spans, 502 feet each, with

a rise of 47 and 44 feet, respectively. Piers go down to solid rock, and above low water are faced with Maine granite with limestone filling. Each span has four segmental arch trusses in vertical planes with parallel chords 12 feet apart. The chords are made of chrome steel tubes 16 inches in diameter, each being formed of six separate staves bound together. The sections are in 12-foot straight lengths with blocks at the joints to form the curve. The upper deck is 54 feet wide and is used for carriage and pedestrian travel, while the lower deck has two lines of railroad between the two outer trusses with a clear height underneath the bridge of 144 feet at the center. The arch ribs having fixed ends without hinges, are well braced together with struts and diagonals. The bridge proper

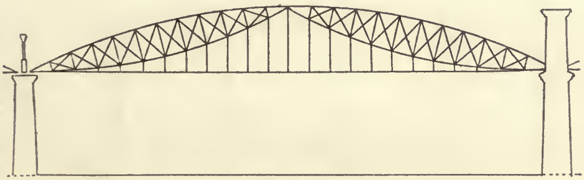


Fig. 208.

is 1580 feet long, and including the approaches is 1,700 feet, the cost of the bridge alone being $5,300,000, or $3,150 per lineal foot, and the whole cost, including the tunnel under the city, $9,000,000 to $10,000,000. It is the longest arch with fixed ends and the first extensive use of steel for bridges. It was erected on the cantilever principle, without falsework, by placing corresponding pieces symmetrically at either side of the river piers, in a manner similar to that suggested by Brunel and Telford for their proposed arches over the Menai Straits. The St. Louis bridge, containing 2,200 tons of steel and 3,400 tons of iron, was severely tested after completion with a line of fourteen locomotives on one track. The bridge was designed by **Capt. James B. Eads,** and was erected under his direction with Col. Henry Flad in charge of construction. Mr.

Eads considered several other forms, including a three-hinged bridge with two lenticular ribs meeting on a center hinge, with suspended floor (Fig. 208). Many other arch designs were made by him, including one for a proposed bridge over the Bosphorus. In the same year (1874) a single arch was completed at Pittsburg, Pa., with a span of 150 feet, to carry Forbes Street over two lines of railway. The segmental arch ribs were 51 inches deep with parallel chords and open web, having a center rise of 23 feet. It was a well-designed arch and continued in use until 1898, when it was replaced by a heavier one with plate girder ribs. In the following year (1875) an interesting but very light railroad arch viaduct was erected over the Retiro river in Brazil (Fig. 209), 165

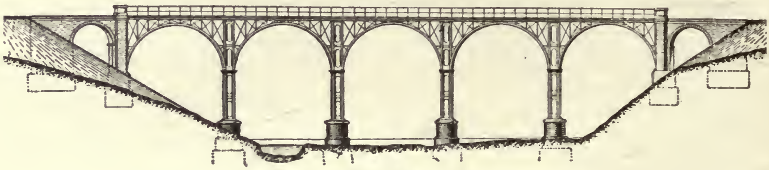


Fig. 209.

miles from Rio de Janeiro. The five metal arch openings of 49 feet 2 inches have a 20-foot stone arch approach at each end, the entire length being 357 feet. The arch ribs are each made of two old rails riveted together with a plate between them.

376. The Rheinhausen railroad bridge over the Rhine (1873), designed by Hartwich, similar to the old Coblenz bridge, has side spans and a swing truss in addition to its four river spans. The Margaret bridge over the Danube at Budapest (1875) is unusual in having three separate sections meeting at a center pier in the middle of the river. Each of these sections contains three arch spans with vertical and diagonal spandrel bracing supported on light intermediate piers. A similar concrete Y bridge has recently been built

at Zanesville, Ohio. **The Pia Maria bridge** over the Douro river at Oporto, Portugal (1877) (Fig. 210), the work of T. Seyrig, is one of the boldest metal arch designs executed, ranking with the later one at Oporto, the Garabit, and the Kaiser Wilhelm at Mungsten. The deck is supported on two crescent-shaped ribs of 525-foot span and 33-foot center depth, bearing on hinges at the end. The ribs, 13 feet apart on centers at the crown, slope out to 49 feet apart at the shoes. The rise of the lower chord is 123 feet, which is 200 feet above the water. At the ends are five approach spans of 94 feet each, two at one end and three at the other. The arch contains 500 tons of iron and the total weight of center structure in-

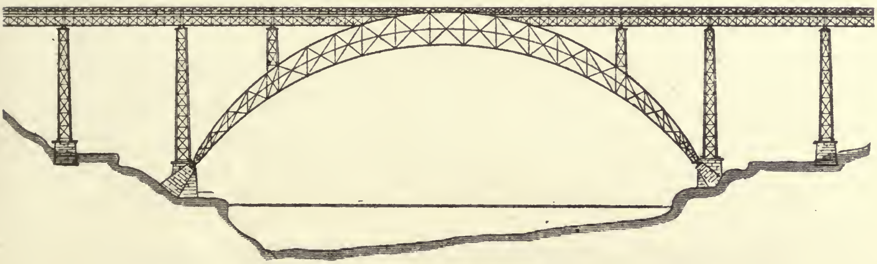


Fig. 210.

cluding arch and floor supports, is 720 tons. The arch was erected by the cantilever method without falsework, and a single line of railway passes over it at a height of 251 feet above water. Other interesting bridges of this time in Europe are those over the Tauber at Weikersheim (1869), over the Neckar at Heidelberg (1876), and the Main at Frankfort (1877), the Erdre near Nantes (1877), and the Moselle river bridge at Guls, in 1878. The Ferdinand bridge over the Mur at Graz (1881) has a single span, through tied arch, without center hinge, with floor suspended and stiffened with lattice girders. The city of Berne, Switzerland, has at least three fine metal arch bridges, one of which is **the Schwarzwasser**

(1882), carrying the Berne and Schwarzenberg road 197 feet above the valley (Fig. 211). It is a hingeless wrought iron parabolic arch span of 374 feet, and is the largest metal arch in

Fig. 211.

Switzerland. The two ribs have a rise of 70 feet and vary in depth from 5 feet at the crown to 11½ feet at the springs. It frequently happens that the building of a bridge is the means of increasing land values sufficiently, not only to pay for the cost of the bridge, but also to enrich its projectors. Land that has remained unused because inaccessible, will often after the building of a bridge become very valuable. This was the case with the **Kirchenfeld at Berne** (Fig. 212), built in 1882 for the purpose of opening up an outlying and un-

Fig. 212.

developed district. The bridge contains two deck arch spans with short lattice trusses at each end, and is 750 feet long, with deck 115 feet above water. The framing is very light and lacking in stiffness, but the design is artistic and presents an attractive appearance. The third metal arch at Berne is the Kornhaus (Cornhouse) bridge over the Aar, 1897, described later. The city of Berlin has a number of ornamental wrought iron bridges, including the Michael (1879), the Mar-

schall (1882), the Sandkrug (1883), the Lutzon bridge (1884), and one near the Muhlendamm (1894) over a branch of the Spree. The Franzens bridge over the Danube canal at Vienna (1885) with a span of 174 feet, is a three-hinged steel arch of small rise with a 27-foot opening through each abutment, for streets parallel with the canal. It has a solid steel trough

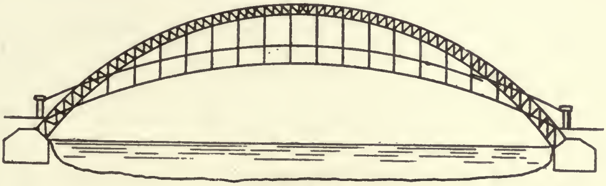


Fig. 213.

floor, cost $160,000 without approaches, and replaced an old suspension bridge. The upper or Wettstein bridge at Basle, with three deck spans, was completed in 1882.

377. At Bedford, in England, are two very interesting metal bridges over the river Ouse, one being a foot bridge (Fig. 213) with a span of 100 feet, with open lattice arch ribs

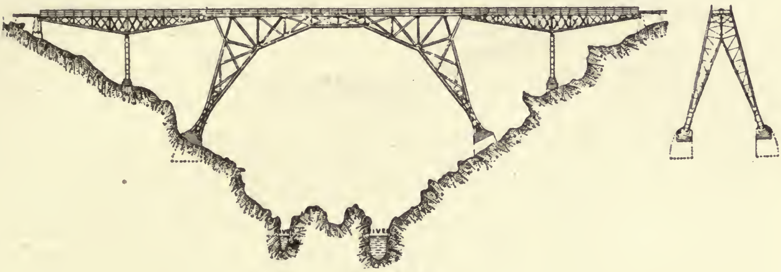


Fig. 214.

rising above the floor and an underneath clearance of 15 feet for boats. The other is a larger one at the same place, with a length between abutments of 200 feet and a width of 35 feet, ornamented on the face with cast iron panel work. M. Max Ende, and R. E. Cooper, 1884, designed the Blaauw Krantz viaduct (Fig. 214) over a ravine at Cape Colony, Africa, which

has a center 230-foot opening of very unusual form. The two truss frames are united at the middle but at the ends they separate to bear on four individual masonry pedestals. The designer states that "while the plan has quite an uncouth appearance on paper, the bridge is imposing when observed from underneath." In any case the design shows much originality.

378. **The Garabit arch** over the Truyere (Fig. 215), in the south of France (1885), is similar to the Pia Maria arch at Oporto, and was designed by the same engineer. The span

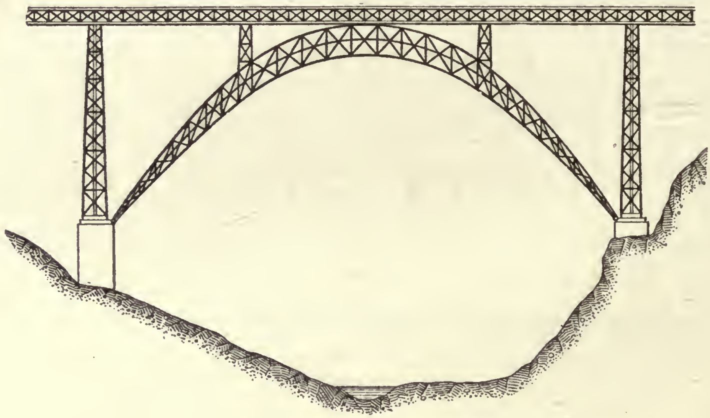


Fig. 215.

is 540 feet, with the deck 406 feet above the water, and is the highest iron arch in the world. The two parabolic, two-hinged arch ribs are crescent shaped, 33 feet deep at the center, 20½ feet apart at the crown, and 65½ feet at the shoes, and the center line is the parabola for uniform loads. A single line of railroad is supported on cross beams between lattice girders 17 feet deep and 16½ feet apart, and below the track is a foot walk for inspection. The whole structure contains 3667 tons of metal and cost $620,000. One-eighth of the span at each side was erected on falsework, and the remainder can-

tilevered out from the adjoining spans. Erection was greatly facilitated by constructing a temporary wood bridge, 100 feet high and 500 feet long, under the arch at a cost of $4,000. Besides the central span, it contains three others of 182 feet and two of 170 feet, with 2,460 feet of masonry approach. All towers have a batter of 4 per cent longitudinally, and 12 per cent transversely. The method of using half through, instead of the usual deck construction, prevents a train from leaving the bridge in case of derailment, and has since been used on the Leithbridge viaduct in Western Canada. **The Luiz I. bridge** over the Douro (1885) has a clear span of 566 feet, with upper and lower roadways (Fig. 216). It differs from all previous arches by having the ends tied together with bars under the lower floor, thereby eliminating side pressure

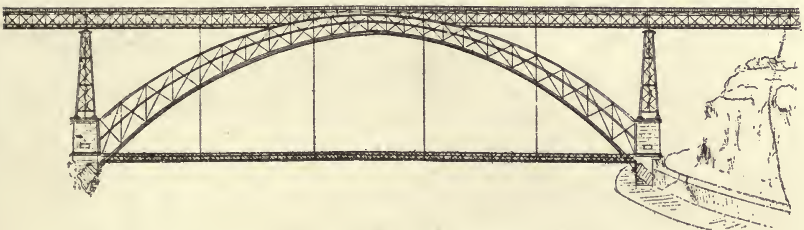


Fig. 216.

on the abutments. The bridge is 1,278 feet long, and the upper road is 160 feet above the lower one and 204 feet above the water. The ribs are 26 feet deep and 20 feet apart at the crown, increasing to 52½ feet apart at the shoes. The lower platform with two lines of lattice girder 10½ feet deep and 29½ feet apart, is supported from the arch at the ends and at four intermediate points. This method of tying the arch ends together has since been used on several bridges in Germany, as those at Worms, Harburg and Mainz. The Luiz I. bridge cost $500,000 and both of the Oporto arches and the Garabit in France were designed by T. Seyrig. Competitive

designs were received in 1881 for the highway bridge over the Rhine at Mayence and one by Lauter with two-hinge segmental ribs was accepted. It has five deck metal arches with one of masonry at each end, and was completed in 1885, on the site once occupied by an old Roman bridge. A single arch of 291 feet was placed across the Adige river at Verona in 1885, replacing an old stone bridge of the fourteenth century which was destroyed in 1882. It was a through arch with suspended floor and deck 38 feet wide, the whole with its foundations costing 20,000 pounds sterling.

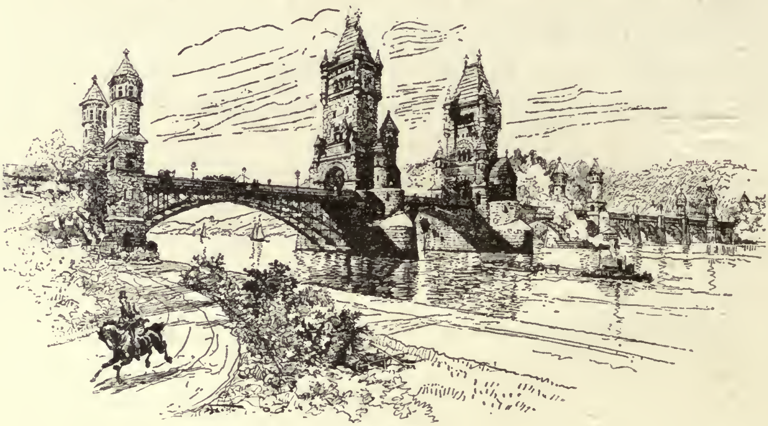


Fig. 217.

379. Arch bridges in America from 1886 to 1890 are those at Lockport over the Erie canal; Richmond, Indiana; St. Louis; Minneapolis; British Columbia; Pulaski, N. Y.; New York City; New Haven; Baltimore; Buffalo, and Rochester. An impetus was given to arch design in America by the appearance of those prepared in 1886 by Captain T. W. Symonds and Mr. Paul Pelz for the proposed **Grant Memorial bridge** over the **Potomac at Washington** (Figs. 217, 218, 219). These are among the finest bridge designs produced in this or any other country. One of them (Fig. 217) had two central

towers 230 feet above water and 160 feet apart, with a double bascule span between them and a series of steel deck arch spans at each side. The proposed site was midway between the Long Bridge and the aqueduct, and Congress proposed a

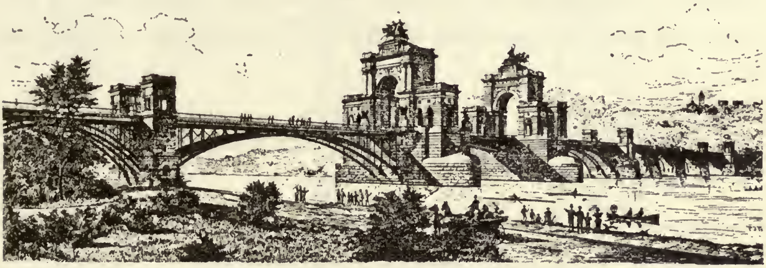


Fig. 218.

$500,000 appropriation as a start, but the project was postponed. The Whitewater river bridge at Richmond (1886) has a 400-foot three-hinged open web arch, with spandrel-bracing, designed by F. C. Doran, and a total length of 576 feet, including two end spans of 64 feet each. The two ribs

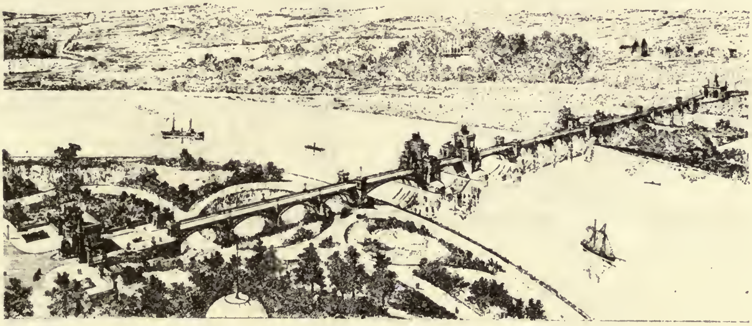


Fig. 219.

are in vertical planes 25 feet apart and all web members are inclined to the vertical.

380. The first bridge to cross the Mississippi river is said to be the suspension at **Main Street, Minneapolis,** in 1855. Be-

coming too narrow to accommodate the increased travel, it was widened in 1888 by the addition of a three-hinged deck steel plate girder arch beside the old one, with a foot walk on one side only (Fig. 220). After the new bridge was completed, the suspension was removed and the other half of the new arch bridge completed in 1891. The first part with three-

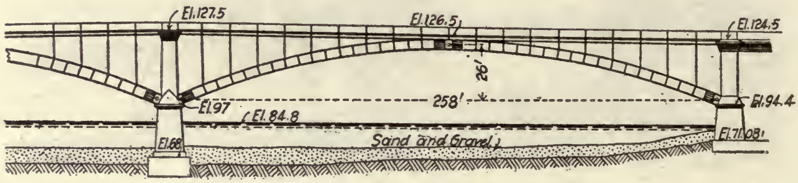


Fig. 220.

hinge ribs had a wood floor and was lacking in stiffness, and the other half was therefore made much heavier with solid floor and hinges at the springs only. Mr. K. G. Hilgard made a design for a bridge at this site in 1886 with a single arch of 520 feet and ribs rising above the roadway from which the floor was suspended. The second large arch bridge to cross

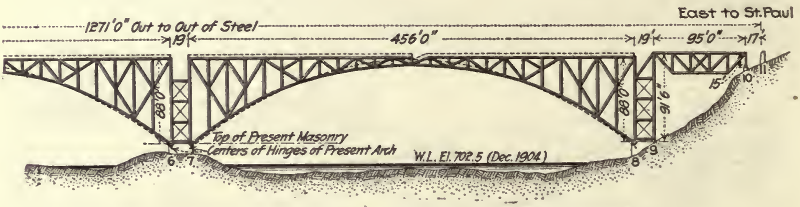


Fig. 221.

the Mississippi river at Minneapolis was begun in 1888 at Lake Street with two spandrel-braced, three-hinged arch spans of 456 feet (Fig. 221). It forms a connection between the riverside parkway systems of Minneapolis and St. Paul. The two arch ribs are vertical and were erected over the ice during the winter season with full timber centering. Diagonals

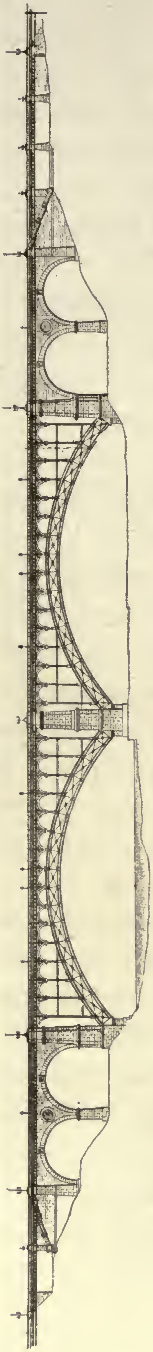


Fig. 222.

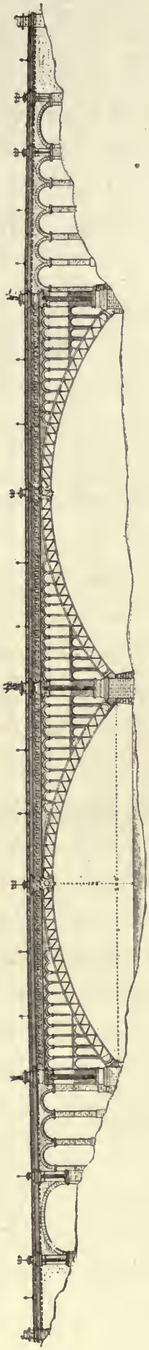


Fig. 223.

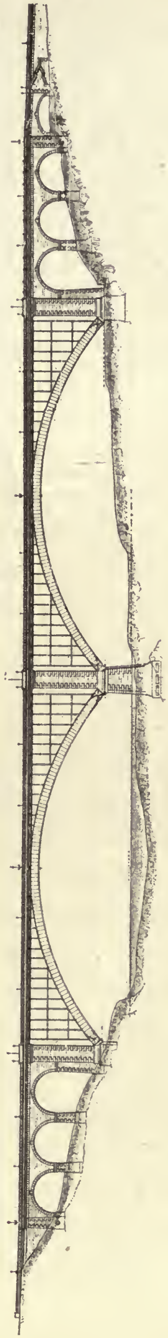


Fig. 224.

are pin-connected, but other members are riveted. The two spans are disconnected from the adjoining framing, thus preventing cantilever action, and it is still the largest three-hinge arch in America. In 1905 the road was widened from 18 to 33 feet to carry two lines of electric car tracks, and a new center truss was added midway between the original ones without moving them.

381. Competitive designs were invited in 1886 for the **Washington bridge,** to cross the **Harlem river** at 181st Street, New York, and nineteen designs were presented, including several arches, one of which, by Mr. Hutton, was accepted. A design by C. C. Schneider (Fig. 222) had two central spans of 410 feet and open web parallel chord arch ribs. It had a series of small arches below the cornice between the spandrel columns, and an estimated cost of $2,075,000, being awarded the first prize in the competition. The second prize was given on a design by William Hildebrand, which had twin parallel chord open web arches of 540 feet (Fig. 223), exceeding those at St. Louis. A design very different from the others, proposed by George Harding (Fig. 151), had a central span of 450 feet, and side spans of half that length, but was not seriously considered. The bridge as built (Fig. 224) has two 510-foot steel arch spans with three 50-foot stone arches at each end, and a 56-foot flat stone arch over a driveway on the east side. The total width of 80 feet consists of a 50-foot road and 15-foot walks. The whole length is 2,375 feet, and the deck is 141 feet above water, with a clearance of 133 feet beneath. The building of the bridge was commenced in 1886 and completed three years later. The center opening has six steel plate girder two-hinged arch ribs in each span 13 feet deep, spaced 14 feet apart, with 92-foot rise. It contains 3,342 tons of steel and cost $2,850,000, which is equivalent to $1,200 per lineal foot. Other bridges of 1890 in America are those at Rock

Lane, New Haven; Cedar Avenue, Baltimore; two park bridges at Buffalo, and the Genessee river bridge at Rochester. The Rock Lane bridge has two vertical plate ribs 16 to 20 inches deep without spandrel diagonals, and an asphalt floor on two layers of plank. The Cedar Avenue bridge has three ribs 12 feet apart with bottom chords bent to a continuous curve and plank floor on wood joist. Panels are open web lattice, excepting in the center, which has a plate web. The Driving Park bridge (Fig. 225) over the **Genessee river at Rochester**, N. Y. (1890), is the work of L. L. Buck, and

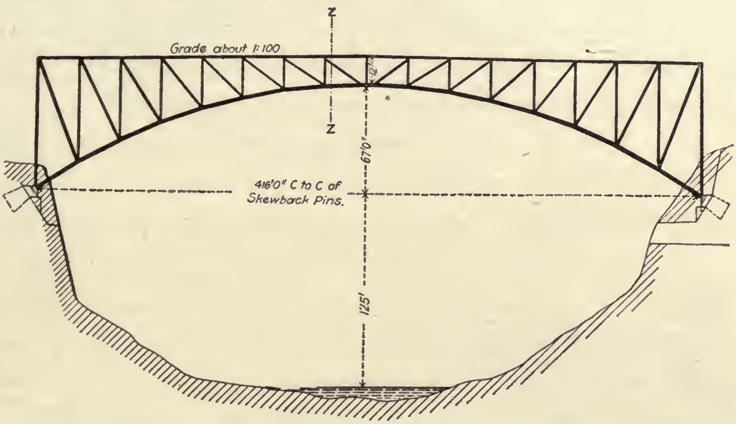


Fig. 225.

the prototype of his larger railroad arch at Niagara. The two open-web spandrel-braced arch ribs of 416 feet and 67-foot rise, have top chords rising slightly towards the center. Trusses are 20 feet apart at the crown, sloping to 46 feet at the shoes, and although the intention at first was to erect the arches cantilever, false work was finally used. All material is wrought iron with riveted connections and the total weight, including approach spans, is 700 tons. The floor is of 3½-inch oak on the road and 2½-inch on the sidewalks.

382. The first appearance of the cantilever arch was in

1890, in the **Hawk Street viaduct** (Fig. 226), at Albany, N. Y., which is a three-hinge spandrel-braced arch with a

Fig. 226.

360-foot central span carrying a highway over a gulley and three other streets, on twin arch ribs. The deck has granite block paving on the roadway and asphalt sidewalks, and the entire cost was $90,000. The 180-foot shore spans have each a 114-foot cantilever arm and a 66-foot end span. Other cantilever arches are those over the Viaur river in France, the Elbe canal at Molln, the Paris Exposition bridge, over the Seine, and railroad bridges in Alaska and Costa Rica.

383. Pont du Midi (1888) over the Rhone at Lyons, France (Fig. 227), forming a connection between La Mouche and Perrache depots is very ornate, with three flat deck arch

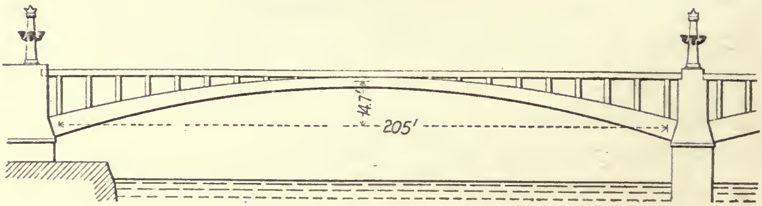


Fig. 227.

spans 66 feet wide and 205 feet long. Each span has eight plate girder ribs rising 15 feet. The Morand bridge over the Rhone at Lyons replaced an old wooden pile bridge of 1774. Beneath the arch at one side is space for a tow path 40 feet wide, with 8-foot head room, and at the other side is a similar but narrower path only 9 feet wide. The Garibaldi bridge over the Tiber at Rome, near the Island, has two spans 174 feet long and 66 feet wide, with granite columns at the ends, a central pier 39 feet thick, and stone pavement. The cost

of the bridge is said to be $720,000, of which $200,000 was for the 1,680 tons of metal work. In contrast to this is the similar bridge of Commerce at Liege, with two spans supported on a slender center pier, with arches thrusting against each other rather than against the pier. The single span parabolic open web arch over the **Adda river at Paderno** (1889) (Fig. 228) is one of the longest and highest, with a span of 492 feet and deck 265 feet above water. The arch ribs, 16½

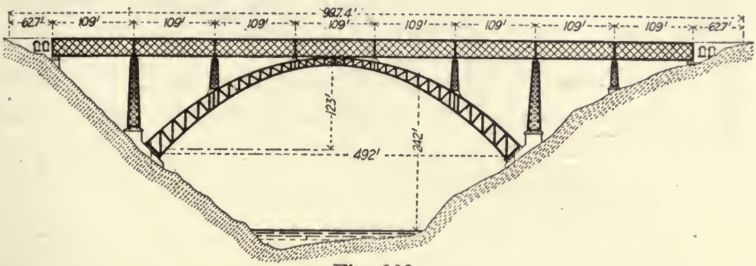


Fig. 228.

feet apart on center at the crown, are battered two inches per foot, to 56 feet apart at the shoes, each of the two ribs being composed of double members one meter apart. The deck trusses are vertical, 20½ feet deep and 16 feet apart, supporting two roadways, the upper one with macadam pavement for highway and pedestrian travel, and the lower with solid trough floor for a single line of railroad. The spandrel towers are battered in both directions according to the usual European practice. It weighs 1,320 tons and is the largest iron bridge in Italy, the erection occupying 10 months and the whole work 18 months, and cost $370,000. Two of the highest bridges in Europe, both built in 1890, are the **St. Guistina arch** over Noce Schlucht, and another over Cerveyrette gorge in Southern Tyrol. The St. Guistina arch (Fig. 229), 460 feet above the valley, is the highest bridge in existence. A cableway was used in its erection, and the stringers are anchored back into solid rock with a temperature adjustment

at one end, the anchor chamber being reached through tunnels from the face of the cliff. The two ribs are vertical and 15 feet apart and the deck has a plank floor on steel joist, the whole weight of metal being 105 tons. The bridge over **Cerveyrette gorge** near Briancon, is 279 feet above the valley and supports a 13-foot roadway on two light parabolic arch

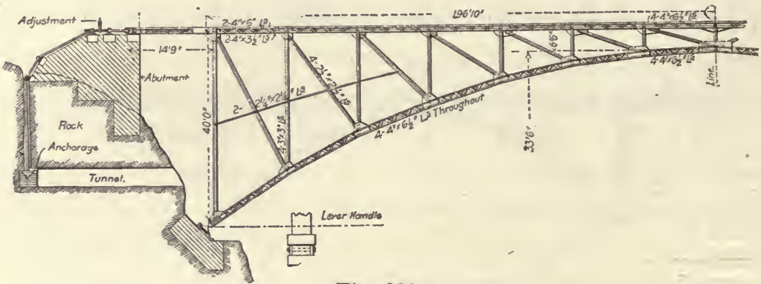


Fig. 229.

ribs. The bridge contains 120 tons of metal, of which 80 tons is in the arch. The wrought iron arch (Fig. 230) over the Wear near Sherburn House, with a single span of 130 feet (1892) is the work of Mr. C. A. Harrison.

384. Among the many bridges over Loop canal at Belle Isle Park, Detroit, is a small three-hinge metal arch with solid

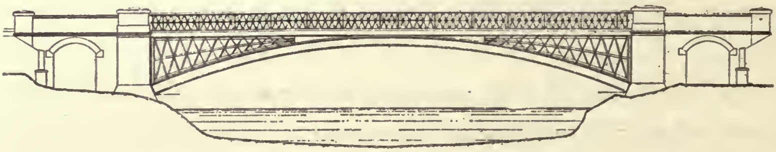


Fig. 230.

ribs which is worthy of mention. Some similar ornamental bridges (1893) were placed in **Lake Park, Milwaukee,** the designs of Mr. Oscar Sanne. One with a clear span of 50 feet and length of 90 feet, has a 26-foot roadway paved with asphalt on buckle plates, and two 7-foot walks covered with cast iron plates. Six steel ribs with end hinges, the outer one be-

ing faced with ornamental cast iron, support the deck, which is protected with iron railings. The total cost, including masonry, metal and paving, was $10,800. Over the North and South Ravines near the Government lighthouse in the same park are two bridges of artistic design, each having a span of 87 feet, and the two costing $36,500. Each bridge has six two-hinge steel arch ribs supporting asphalt roadways and cement sidewalks on beams and buckle plates. The abutments are of fine coursed ashlar, surmounted with a Bedford stone railing, but over the arches the railing is of ornamental iron. At the four abutment corners adjoining the opening are ornamental posts, supporting a cluster of lamps, and at the abutment ends are pedestals with figures of lions.

385. Several interesting arch bridges were used by the Canadian Pacific railroad in rebuilding its line through the mountains of British Columbia. Of these, the **Stony Creek bridge** (Fig. 231) is probably the best known. It crosses the creek and valley on a high deck steel arch 300 feet above the

Fig. 231.

valley in a very picturesque place. The sides of the valley are so steep and rocky that the site was naturally inviting for an arch design. When first building the road in 1885 the engineers, Messrs. W. A. Doane, G. H. Duggan and T. K. Thomson, carried the track on a wooden bridge with four spans of Howe truss on timber towers, and the wood remained in use for about ten years, when it was replaced. The steel arch has a span of 336 feet and a rise to the under chord of 80 feet. The curved arch trusses are 26 feet deep at

the ends and 20 feet at the center, 24 feet apart at the crown battering out 1 in 10 to the shoes. The trusses are pin connected, but all bracing is stiff and riveted. The riveted deck trusses carrying the track are 9 feet deep, and 9 feet apart on centers, and the total length, including the two end spans, is 485 feet. The weight of steel in the arch is 524 tons and in the entire structure 771 tons. The chief engineer for the railroad company was P. A. Peterson, and H. E. Vautelet, bridge engineer. The bridge over **Salmon river** (Fig. 232)—a branch of the Fraser—near Keefers Station, British Colum-

Fig. 232.

bia (1893), is located 34 feet south of the old wooden Howe truss bridge, which was designed by the same engineers who built the Stony Creek bridge. The old bridge had a center span of 210 feet with a 90-foot span at each end supported on two high timber towers. The new steel arch has a center span of 270 feet and a rise of 50 feet to the under side of arch, with the deck 123 feet above water. The ribs are 60 feet deep at the ends and 10½ at the center and at each end are two steel plate girder spans. The arches are three hinged, 16 feet apart at the upper chords, battered out 1 in 10 to the ashlar masonry abutments, which are placed in seats cut into the rock. The use of rod lateral bracing to avoid the expense of bending the lateral plates was considered, but was not adopted because of its insufficient stiffness. **Surprise Creek** bridge (Fig. 233) is similar to that at Salmon river excepting that the shoes are at different levels, making the arch ribs unsymmetrical. It is a single span spandrel-braced steel arch, 290 feet between end pins, 70 feet deep at one end and 92 feet at the other, with a center depth of 16 feet. At one end is

a plate girder span of 56 feet and a similar one of 108 feet at the other end. The upper chords are 16 feet apart for single track, battering out towards the shoes at the rate of 1 in 8. Shoes have ball and socket bearing, similar to other larger spans on the same railroad. The arch is three-hinged,

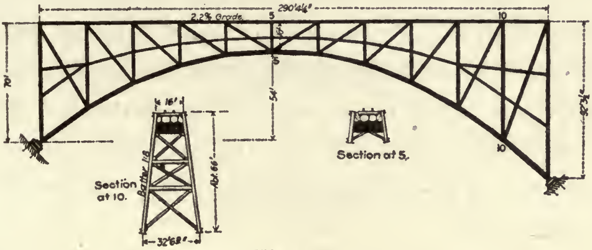


Fig. 233.

pin-connected, with riveted bracing, and the deck is 180 feet above the valley. The reported weight of steel in the main span is 520 tons, which is much heavier than other similar bridges.

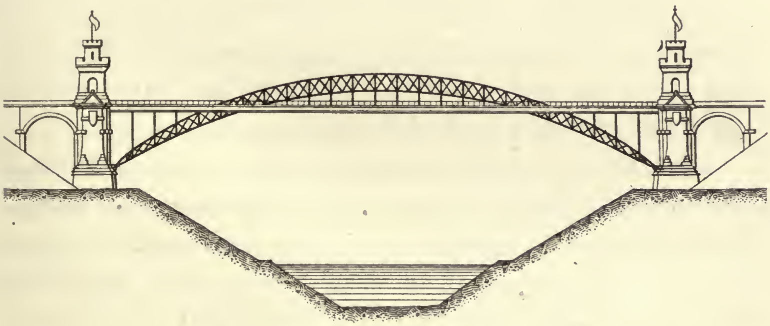


Fig. 234.

386. Two of the largest iron arches in Europe are the Grunenthal and Levensau bridges over the North Sea Baltic Canal, completed in 1892 and 1894, respectively, with space for both railway and highway, both bridges having high level roadways and clearance beneath for ships. **The Grunenthal** (Fig. 234) has two crescent-shaped ribs of 513-foot span and the

Levensau arch has a 536-foot span supported on a pair of segmental two-hinge open web ribs in vertical planes, the whole containing 2,800 tons. The unusual feature of the **Levensau bridge** is the provision for resisting wind pressure. The floor is suspended, allowing wind stresses to be freely transmitted to the upper truss, and the whole was erected on full timber centers. Provision was made for two tracks, but only one was placed at first, the place for the other one being used temporarily for a highway. The arch foot bridge over a branch of the Spree near the Muhlendamm at Berlin (1894) has a single through tied arch with suspended floor and a span of 190 feet.

387. In 1893 a high-level bridge over the river Mersey at Liverpool, was proposed by J. J. Webster and J. T. Wood, with three through arch spans of 1,150 feet and a deck 150 above the water. In addition to the regular approaches they proposed six lifts or elevators at each end from the lower street to the upper bridge level. The main arch ribs were shown of eight octagonal steel tubes braced together, with hinges at spring and crown, the whole bridge having an estimated cost including land of $8,650,000.

388. In the four years preceding the opening of the large arch bridges at Niagara, about fifteen other steel arch bridges were completed in America. The Brooklyn-Brighton bridge over Big Creek at Cleveland, Ohio (1894), composed chiefly of alternate trestle spans of 28 and 56 feet, contains an open web three-hinge steel arch with 168-foot span. The center line of the lower chord is a parabola, but the upper panel points are on three straight lines. The trusses are 26 feet apart on centers and the total cost of the viaduct, including land, was $170,000. An arch bridge (Fig. 235) over a pond in Riverside Cemetery, Cleveland (1896) has two crescent-shaped parabolic ribs 142 feet long with a rise of 27 feet and

5 feet crown thickness. The middle half has an open lattice web, while the two end quarters have solid web plate. The arch ribs are in vertical planes and support the roadway girders at only two points. The Walden highway arch bridge at Lake Forest, Ill. (1895), crosses a drive and valley with

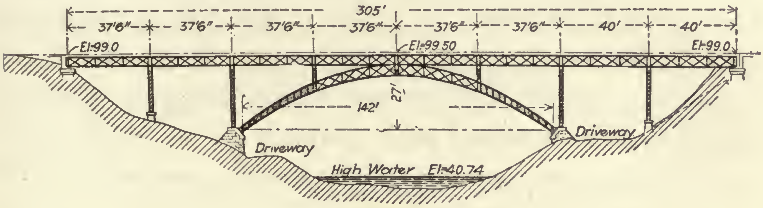


Fig. 235.

solid plate girder arch ribs and radial posts from the arch to the floor beams. The Grand River arch bridge at **Lansing, Mich.** (Fig. 236), is deserving of special notice, chiefly for its great width of 116 feet and for its heavy floor. Each of the

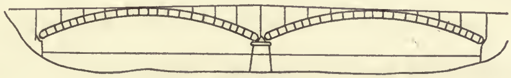


Fig. 236.

two spans has six steel plate girder ribs 4 feet deep and 18 feet apart. The brick pavement is laid on concrete over brick arches between steel floor beams, but the walks have a plank floor. It was designed by E. J. Landor and completed in

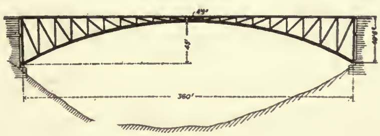


Fig. 237.

1895 at a cost of $60,000. **Panther Hollow bridge** in Schenley Park, Pittsburg, Pa. (Fig. 237), carries a roadway over Panther Hollow, a ravine 120 feet deep. It crosses from the Phipps Conservatory to the Speedway, with a 360-foot steel

arch and two 28-foot stone arches at each end. The center span has four steel three-hinged vertical ribs 13½ feet apart on centers, supporting a 60-foot deck, with 10-foot walks on cantilever brackets, paved with asphalt on steel trough flooring. The parabolic arch ribs have a rise of 45 feet and a crown thickness of 5 feet, making end heights of 50 feet. The whole bridge is 615 feet long, and at the ends are pedestals mounted with bronze figures of panthers. It was completed in 1896 at a cost of $170,000. The other bridge in Schenley Park, known as **Schenley Park bridge,** is quite similar to the last-named one and crosses a ravine 100 feet deep with a 360-foot steel arch and a 50-foot stone arch at each end. It is 620 feet long, 80 feet wide, with asphalt road and cement walks,

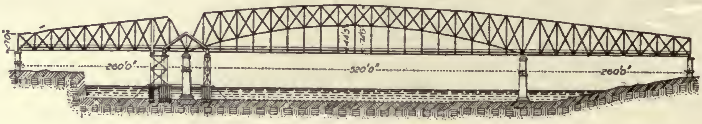


Fig. 238.

and was completed in 1897, under the direction of H. B. Rust, at a cost of $240,000. The South Twenty-second Street bridge (Fig. 238) was the first free bridge over the Monongahela river at Pittsburg. The central 520-foot span consists of a pair of three-hinged arched trusses of the Bonn type, 60 feet deep at the ends and 30 feet at the center, with a lower chord rise of 44 feet. At each side of the center is a 260-foot span connected by false members with the larger span, the upper outline resembling somewhat the Northfield cantilevers. Trusses are 32 feet on centers, giving space for two lines of car tracks and a paved road of concrete on trough floor. The 8-foot walks at each side have asphalt over concrete and buckle plates. It was opened in 1897, but ten years later the piers required very extensive repairs. A bridge over the Black river at Watertown, N. Y., has two spandrel-braced ribs

between rock side walls, and was erected with three hinges, but the crown hinge, which was on the line of the upper chord, was afterward discarded and the parts riveted up solid with splice plates. The center 100 feet has solid webs, while the remaining quarters have two panels of open lattice at

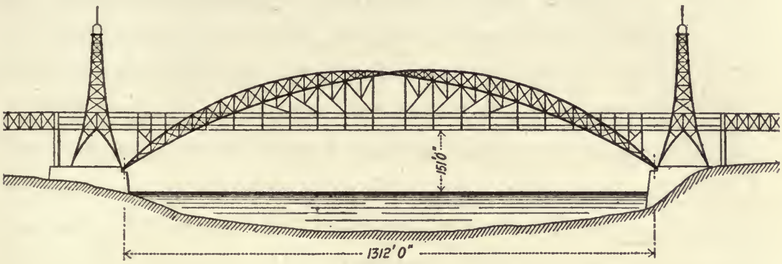


Fig. 239.

each end. It carries a solid pavement on buckle plates and replaced an old suspension which had a span of 175 feet.

389. In the competition for a bridge over the **St. Lawrence river at Montreal** (1897), three designs were submitted by Messrs. Francois Bicheroux, Charles Steiner, and C. R. Grimm, for high level arch bridges with single spans of 1,200

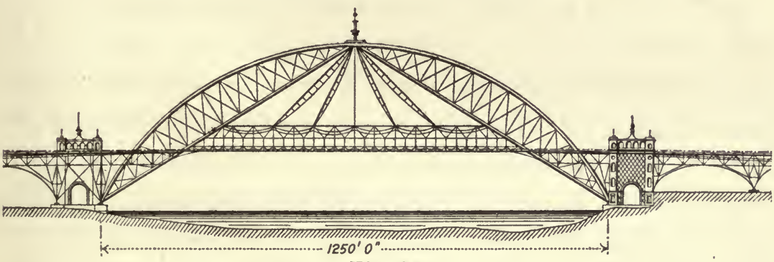


Fig. 240.

to 1,300 feet, and floors 150 feet above the water. The first of these (Fig. 239) had high metal towers at each end of the main span dividing the central bridge from the viaduct approach, and it, and the second design (Fig. 240) had hinges at the ends and center, while Mr. Grimm used two-hinge parabolic arch ribs of crescent form. Three years previous, Mr.

Steiner prepared a somewhat similar arch design for a proposed bridge to cross the North river in New York City, and Max Ende, the French engineer, designed a 783-foot arch span to cross the Thames at London, with an under clearance of 90 feet. M. Ende proposed elevating street traffic to the bridge on moving cars or elevators somewhat like those on the inclined railways at Cincinnati, Pittsburg, and Hamilton, Ont., the last of which was built under the direction of J. W. Tyrrell, engineer. The estimated cost of the Thames bridge, including abutments, platforms, and machinery, was $1,210,000. A similar bridge was proposed for crossing the Garonne at Bordeaux (Fig. 241), with a span of 400 meters, and another, with a span of 735 feet, proposed by Clark Reeves and Co.

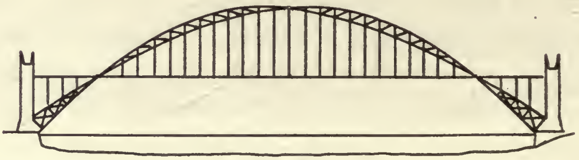


Fig. 241.

A design for a proposed metal arch, with a central span of 1,000 feet and 250-foot spans at each side, was made in 1898 by Sir Bradford Leslie, to cross the Hoogly river at Calcutta. The intention was to have two decks and a 200-foot double bascule opening beneath the central arch, which was high enough above it to give ample clearance for ships. In 1897, W. B. Parsons made preliminary plans for a viaduct 3,000 feet long over Sherman's creek, from Fort Washington to Kingsbridge, N. Y., including a 516-foot crescent arch, with an estimated cost for the whole viaduct of $1,400,000. Other bridges of the period in America are those at Spokane (1893), Bentleyville and Youngstown, Ohio (1895), Forest Hills, Boston (1896), Niagara Falls canal (1896), Six Mile Creek at Ithaca (1896), and those over the canals at Buffalo, N. Y., and Ham-

ilton, Ont. (1897). The proposed Hoogly arch was quite similar to a design made by R. M. Ordish in 1885, for the proposed Tower bridge at London.

390. During the three years previous to opening the Bonn bridge in 1898, Europe produced several large arch bridges, the principal ones being those at Mungsten, Viaur and Berne. The Queen Carola bridge over the Elbe at Dresden (1895), with three arch spans over the river and stone approaches at each end, has very heavy piers with elaborate and heavy detail, and bronze figures at the north end, placed in 1899. **A road** bridge over the wild mountain Versam Gorge (1897), on the road from Bonadiz to Ilanz, is 230 feet above the valley and has two spandrel-braced ribs supporting a macadam floor on

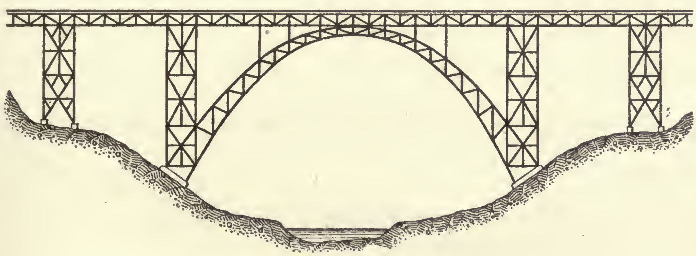


Fig. 242.

solid metal troughs. The almost vertical rock cliffs made the arch an economical type for the location. The **Kaiser Wilhelm bridge** over the Wupper river at Mungsten, Prussia (Fig. 242), is one of the largest in Europe. It was completed in 1896 from designs by A. Rieppel, at a cost of $687,500. The viaduct carries a double track railroad between Remscheid and Solingen, on lattice girders with a solid trough floor, and cantilever walks at each side, the deck being 350 feet above the valley. The main arch, which has a span of 557½ feet between tower centers, has two parabolic ribs 16 feet apart at the crown, sloping out to 83 feet at the base. The German government invited designs for crossing the valley either

on trestle, cantilever or arch, the last being adopted. The erection occupied twenty-two months and was very expensive. Towers were erected from temporary wooden staging inside of each, and the 148-foot spans were built on platforms made of light bridges hoisted bodily up between the adjoining towers. Temporary shops were also built at the site, and the center arch was cantilevered from each side and anchored back to the adjoining framing. The whole bridge contains 5,600 tons of steel and is equipped with three permanent inspection travelers, giving access to all parts. The arch at the end is built into the towers, and was first erected with three-hinge bearings, but the center and end hinges were removed in turn, and the whole made fixed and square bearing. It is now the longest fixed end arch in Europe. **The Viaur viaduct** (Fig. 243), on the road from Carmaux to Rodez in France, carries a single track at a height of 385 feet above

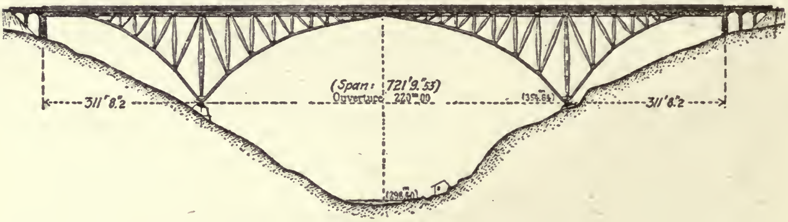


Fig. 243.

the valley. The center span is 721 feet and the two end spans 311 feet each, with a clear length between abutments of 1,345 feet, and a total length of 1,509 feet. At the ends of each side span are short suspended spans of 85 feet, bearing on the abutments and on the cantilever brackets. The arch ribs are 19½ feet apart at the crown and they slope out on a 25 per cent batter to 109 feet at the shoes. A permanent walk and tramway beneath the floor afford opportunity for inspection. Compression members are tapering, and larger at the center than at the ends. The trusses are all riveted, the

total weight of the metal 4,290 tons, and the entire structure cost $490,000, of which $47,000 was for the masonry. Several preliminary studies were made, resulting in the selection of a cantilever arch, as built. **The Kornhaus bridge** (Fig. 244), the third large arch over the Aare at Berne, has a center open web lattice arch of 384 feet, with five smaller plate

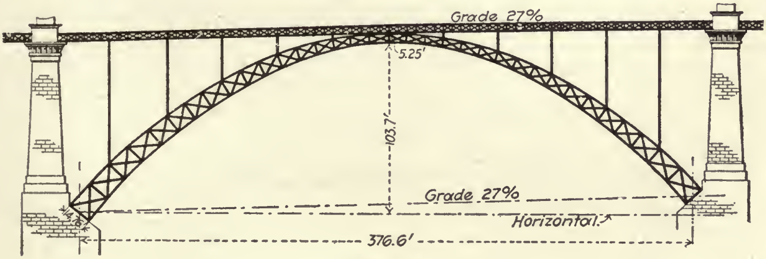


Fig. 244.

girder arches at the side. The main span contains 1,000 tons of steel with 500 tons more in the smaller spans, and the whole bridge, complete, cost $426,000. The ribs are parabolic, without hinges, varying in depth from 5 feet at the crown to

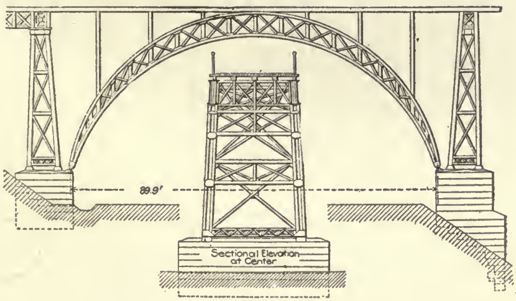


Fig. 245.

15 feet at the springs. The floor is on a grade of 2.7 per cent and is made of wood block pavement on galvanized buckle plates. The ribs are 26 feet apart at the crown and batter out 1 inch per foot to 43½ feet apart at the shoes. Other European bridges of this time are those over the Danube at

Straubing (1896) and the Carlsburg viaduct (Fig. 245) in Denmark, with two arch spans.

391. The opening of the **Niagara railroad arch** marked a new period in American bridge design (Fig. 246). The remarkable example of modern engineering was completed in 1896 at a cost of $500,000. It replaced the old suspension built by

Fig. 246.

Roebling in 1855 with wooden stiffening trusses and stone towers. The arch has end hinges and a span of 550 feet with 114-foot rise, and carries two lines of railroad on the upper deck, with three lines of board walk for the convenience of workmen. The lower deck has a 25-foot highway with 6-foot sidewalks of wood joist and flooring on cantilever brackets. The width between arches at the crown is 31 feet, and they batter out to 57 feet apart at the shoes. The ribs are 20 feet deep at the center and 134 feet at the ends. The upper

deck, 225 feet above the water, is protected by iron railings, as is also the lower deck. The bridge contains 3,600 tons of steel with riveted connections and was erected cantilever with parts guyed back to shore. A three-hinge bridge (Fig. 247) with bottom members in a straight line from shoe to crown was computed by Mr. Schaub, and found to contain

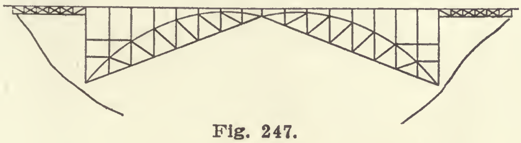


Fig. 247.

less metal than the arch form, though it was less pleasing in appearance.

392. The **Niagara-Clifton** bridge over the Niagara river 1,000 feet below the falls (Fig. 248), has a center arch span of 840 feet with approach spans at each end, and is the longest arch span in existence, though several larger ones have been projected. The two arch ribs have parallel chords 26 feet apart with pin bearing at the ends. It replaced the old suspension bridge of 1858, which had a span of 1,268 feet, and it is the third bridge to occupy the site. It has a deck 46 feet wide, and 200 feet above the water, with two car tracks in the center. The ribs are 30 feet apart at the crown, sloping out to 69 feet at the shoes. The main arch contains 1,825 tons of steel and the whole bridge 2,260 tons. It was erected cantilever, similar to the method adopted for the Mungsten bridge, and opened for travel in August, 1898. Water under it is believed to be about 180 feet deep. The Fairmount

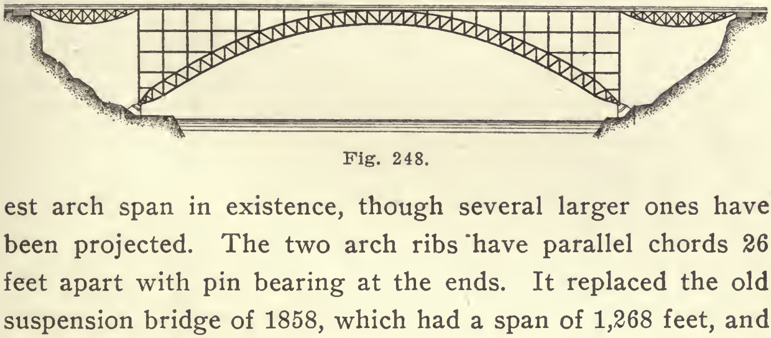


Fig. 248.

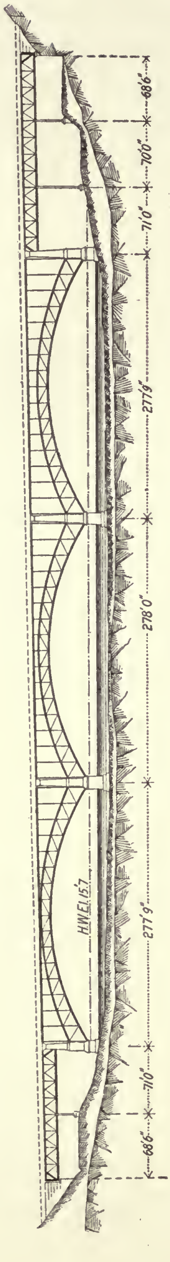


Fig. 249.

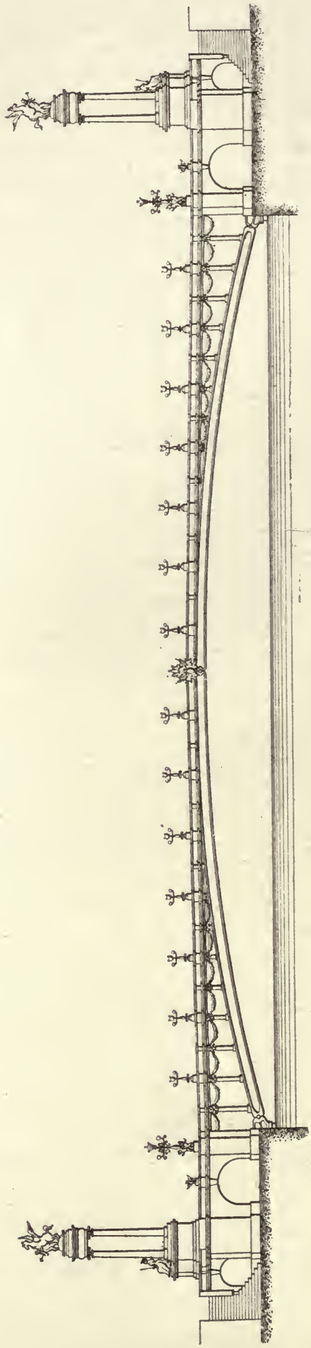


Fig. 252.

arch bridge (1898), over the **Schuylkill river at Philadelphia,** had four three-hinged spandrel-braced arches of 200 feet, flanked at each end with three girder spans. The arches thrust against cast iron shoe boxes on the piers, the thrusts tending to counteract each other. Two lines of electric railway pass over one side with a wood floor beneath, the remainder of the deck, which is 80 feet in total width, being occupied by a carriage way and footwalk with solid pavement. Each span has three vertical ribs 28 feet apart with rigid bracing and buckle plate floor. The bridge contains 3,000 tons of steel, cost $375,000, and was designed by the Phoenix Bridge Company, their design being accepted against much opposition, in preference to a very superior one by C. C. Schneider (Fig. 249). The long arch bridge on **Riverside Drive,** New York, has twenty-two arch spans of 65 feet and one of 130 feet, with a total length of 1,564 feet. It has a deck 80 feet wide with a solid pavement on buckle plates, 75 feet above the valley. The design was not economical, costing $570,000, but was adopted because of its supposed better appearance. The competition of 1898 for the Connecticut Avenue viaduct at Washington evolved three designs with steel arches, one by Mr. Breithaupt having 410-foot center span with 282-foot arches at each side and Melan shore spans. The length was 1,320 feet and width 70 feet, with an estimated cost of $4,00 per square foot of roadway. Another design by Mr. Buck had five similar arches, while the third proposed a central steel arch of 544 feet with four ribs, and 95-foot rise, and four Melan arches with asphalt floor, at an estimated cost of $450,000. A competition the same year for the Massachusetts Avenue bridge over Rock creek at Washington, brought forth an arch design by E. Marburg for an arch cantilever (Fig. 250) 500 feet long and 80 feet wide, with an estimated cost of $200,000. Mr. Marburg proposed

three lines of trusses 28 feet on centers, with asphalt and buckle plate floor. The Fall Creek arch at Ithaca, N. Y., near Cornell College, spans a gorge 150 feet deep, with steep, rocky sides, and an arch was therefore an economical type, as artificial abutments were not required. It has a span of 170 feet with 20-foot approach spans at each end. The two plate girder arch ribs are 5 feet deep and 20 feet apart on centers, made in two straight sections between the loaded points rather than in a continuous curve, and was erected on temporary timber false work. The South Market Street bridge over the Mahoning river at Youngstown, Ohio, 1899, has one segmental two-hinge plate girder arch of 210-foot span and 60-foot rise, with two ribs 28 feet apart, and truss spans of 165 feet at each end. The whole viaduct is 1,610 feet long, composed of trestle spans of 30 to 90 feet on towers 28 feet

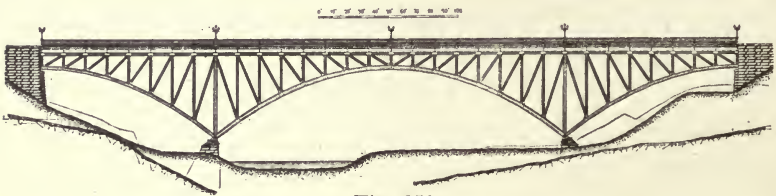


Fig. 250.

wide and 30 feet long with vertical columns. It was designed by C. E. Fowler and the arch was erected on full timber false work. The city of Pittsburg, Pa., erected two solid web arch bridges in 1899 and 1900 carrying Forbes Street over ravines. The first replaced a lighter 150-foot arch of 1874, and has four two-hinge arch ribs of 144-foot span and 6 feet deep, supporting a road 56 feet wide with asphalt pavement and buckle plates, and a double line of electric car tracks. The other bridge, erected in 1900, carries Forbes Street at a height of 94 feet over Nine Mile Run on a three-hinge arch of 190-foot span, with three approach spans of 24 feet at each end. It was designed by Willis Whited, who gives his reasons

for selecting this type. He says that "a braced arch with parallel chords is not suitable for spans less than 300 feet and was, therefore, not considered. Preference was for a stone arch, but the cost was prohibitive and a continuous trestle or combination of trestle and truss span was not artistic enough for the location. A cantilever with curved chords was considered, but its deflection would be excessive, therefore not desirable, and the arch is false. The purpose of a spandrel-braced arch is not so evident as a simple one, for sincerity, which is an essential of good design, is lacking. An arch without hinges, or with only two hinges at the ends, has less material and looks better than a three-hinge arch,

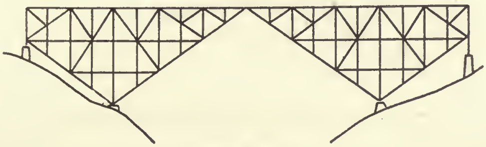


Fig. 251.

but there is usually difficulty in securing an even bearing, and a three-hinge plate girder arch was therefore adopted." It has two vertical arch ribs 6½ feet deep and 36 feet apart, supporting asphalt pavement on buckle plates, with a 3.3 per cent grade. The whole bridge contains 760 tons of iron and steel, and cost $86,000, the center span being erected cantilever, with guys from the adjoining framing. An unusual form of cantilever arch, of the type used at Hawk Street, Albany, and for the Viaur viaduct in France, carries the White Pass and Yukon Railway over a mountain gorge with a center opening of 240 feet (Fig. 251). It differs from these bridges in having the bottom chord straight instead of curved and the profile area suggests a surplus amount of web members for economy. It was erected as a cantilever and the ends afterward blocked up tight. It is quite similar in outline to

a design proposed in 1891, by J. W. Schaub with a span of 500 feet, for crossing the Niagara gorge.

393. In the six years following 1899, several new bridges were erected across the Seine at Paris, the first of which is an ornamental one at the Exposition grounds, connecting the Champs des Elysees and the Esplanade des Invalides. It is 131 feet across and is the widest bridge in Paris, one-half of its width being occupied by the roadway and the remaining half by the two sidewalks or promenades. The bridge is remarkable for its large span of 353 feet and its small rise of only 20 feet, and for the use of cast steel in its fifteen lines of arch ribs, which are slightly less than 9½ feet apart. The erection centers were suspended from overhead trusses, leaving the river unobstructed. Another notable feature was the use of steel caissons which were sunk by the pneumatic process. At each end are ornamental towers, the tops of which are 75 feet above the roadway. The faces and spandrel are ornamented with festoons and panel work in iron, and the balustrade is rich and heavy with round balusters and moulded top. At each end is a profusion of sculpture and on the posts of the balustrades are ornamental standards supporting clusters of lights. The bridge was opened in 1899 and was called **Alexander III.** (Fig. 252) in honor of the czar of Russia. The foot bridge (Fig. 253) over the Seine at Paris (1909) between the Alma and Jena bridges, contains unusual and original features, resulting from special requirements. It was

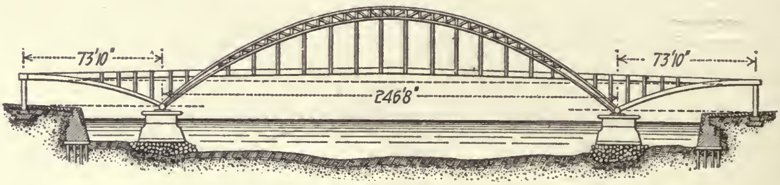


Fig. 253.

imperative that the central 240 feet of the river should not be obstructed with piers or falsework, and a clear height of 28 feet beneath the floor was required for river craft. A through arch with suspended floor was therefore adopted for the central span, and cantilever arms at each side served to anchor back the arch, which was erected with falsework. The bridge is for pedestrians only, has wood joist and floor, and was a part of the improvement for the Paris Exposition of 1900. The parabolic arch ribs are crescent shaped, 6½ feet deep at the center, with open lattice work web through the central portion, and solid web plate at the ends. All connections are riveted, and over the central part is transverse cross bracing.

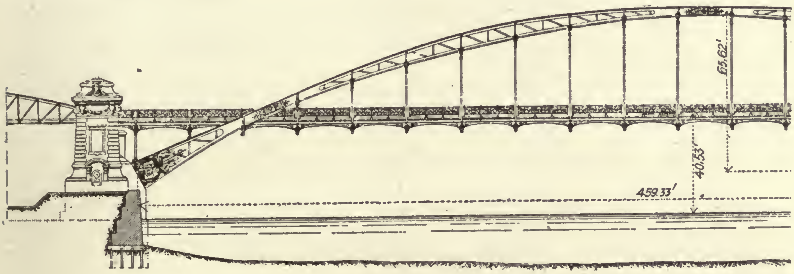


Fig. 254.

394. **The Passy viaduct** over the Seine had a crescent-shaped arch of 281 feet with suspended floor, over one arm of the river. It carried two tracks of the Western Railway of Paris on a curve and on a 1 per cent grade, causing the bridge to have a slight skew. The center line of the arch rib was a parabolic curve and the suspended platform, which was covered with flat plates, was so arranged that it could resist none of the arch thrust. **The Austerlitz bridge** (Fig. 254) over the Seine (1905) carries two tracks of the Metropolitan Railway of Paris on a three-hinged 460-foot arch, which is the longest span of any kind in Paris. A single span without piers, with a clearance of 36 feet beneath the bridge for

BRIDGE OVER RHINE AT DUSSELDORF

boats, was required by the authorities, and these stipulations determined its outline. An earlier design showed arch ribs with hinges at the piers and crown, but this was revised and the lower hinges placed at the floor level, which shortened the distance between them to 107 meters, and made square ended sections between the piers and the floor. The deck, which is independent of the arch and which carries all wind pressure to the abutment, is covered with flat steel plates. At one end is a single through span and at the other, two deck spans. The cost of the substructure was $200,000, and the superstructure $90,000 more.

395. The cantilever arch (Fig. 255) over the Elbe-Trave at Molln (1899) has a 44-foot cantilever arm at each end

Fig. 255.

of the central arch, which has 106-foot span and 25-foot rise. A center hinge was used during erection, but the two halves were afterwards riveted solidly together. Another bridge over the same canal at Lubeck has a single through tied arch, similar to the Spree bridge at Berlin, of 1894.

396. The building of two bridges over the Rhine at Bonn and Dusseldorf marked the beginning of a new system of bridge building in Europe. In the competition for the Bonn bridge sixteen different designs were submitted, and the one which was accepted and completed in 1898 (Fig. 256) has a center 614-foot arch span, which is the longest one in Europe, and second only to the highway arch at Niagara. The trusses are vertical and 29½ feet apart, with a 23-foot roadway between them and 11-foot cantilever walks outside. At each side of the central span are smaller deck arches 307 feet long. The floor has wood block pavement on galvanized iron buckle

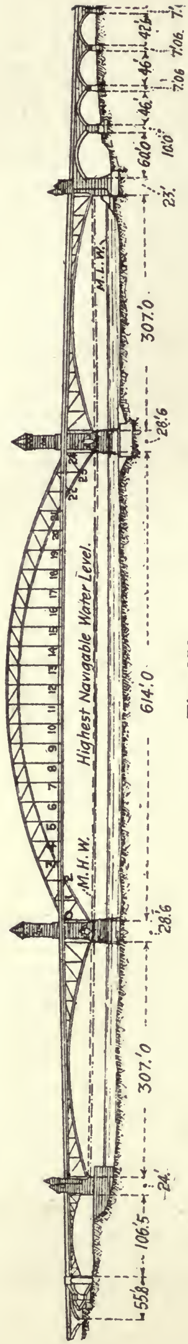


Fig. 256.

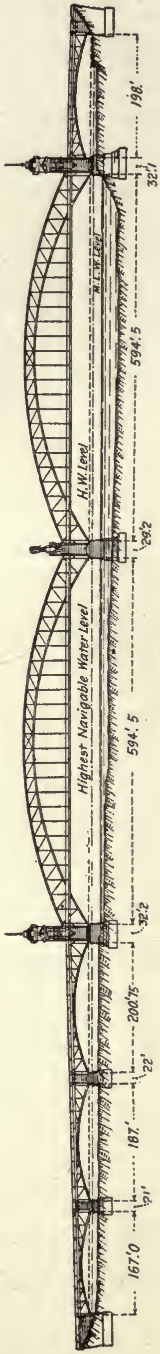


Fig. 257.

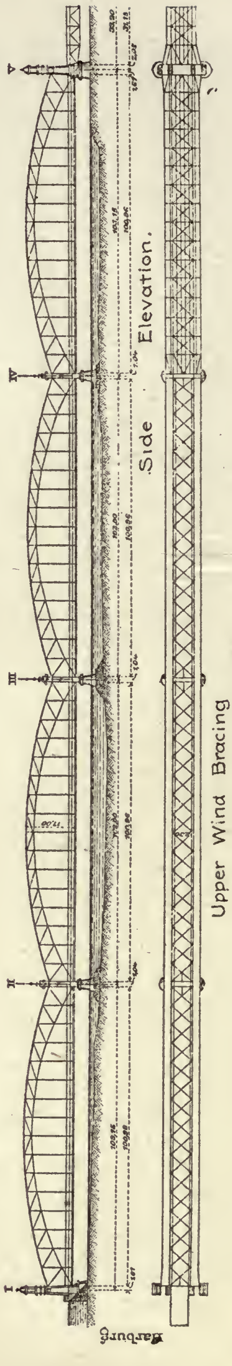


Fig. 258.

plates. Chord sections are formed to a continuous curve, which adds considerably to the amount of metal. The ribs of the main arch vary in depth from 15 feet at the crown to 34 feet at the springs, with a lower chord rise of 97 feet. The structure contains 3,330 tons of metal, was erected on falsework and all joints riveted. It has heavy and elaborate detail on the metal portal, which would hardly be appropriate for other bridges. The engineer was Prof. R. Krohn, who was assisted by B. Moehring, architect. **The Dusseldorf bridge** (Fig. 257), also designed by Prof. Krohn (1898), has two central spans of 595 feet with smaller sides ones of 189 to 205 feet, and a total length of 2,100 feet. The roadway is 27 feet wide and the two cantilever walks 62 feet above the water. The chords of the main span are cicrular arcs 16½ feet apart at the crown and 40 feet at the ends, with a rise of 90 feet on the under side. Trusses are 31 feet 9 inches apart on centers and the bridge contains 5,130 tons of metal and cost, complete, $905,000. The Moselle bridge at Trarbach, the Elbe bridges at Harburg and Magdeburg, and the Rhine bridges at Worms and Mainz, have arch trusses similar to those of Bonn and Dusseldorf, except that the arch ends are tied together by members below the floor and there is, therefore, no lateral thrust on the piers, but vertical reaction only. In this respect the bridges are similar to the Luiz I. at Oporto, which has a second low level platform above the arch ties. These five are arched trusses rather than true arches, but are included here because of their resemblance to those at Bonn and Dusseldorf. The Moselle bridge at Trarbach (1899) has four spans and the **Harburg bridge** (Fig. 258) over the Southern Elbe to Wilhelmsburg has four river spans and six smaller ones of 102 feet each. It has two lines of street railway, with stone block pavement on buckle plates, and cost $428,000. The ends of the central bridge are marked by ornamental

portal towers. The Elbe highway bridge at Magdeburg (1901) has a central span similar to the last with a stone arch at each end.

The **Worms railway bridge** (Fig. 259), built the same year from designs by Schneider and Frintzen for double track, has three river spans with seventeen smaller deck spans of 113 feet at one end, and a total length of 3,054 feet. The trusses rest at one end on expansion rollers and beneath the bridge is a clear height of 41 feet above the water. The floor is planked over and at one side is a foot walk on cantilever brackets. The piers have concrete centers faced with stone, and the bridge framing contains 5,430 tons of steel, the whole costing $800,000. The highway bridge over the river

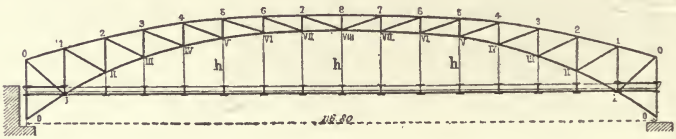


Fig. 259.

Rhine at Worms (1900) is a three-span deck arch, the center one being slightly longer than the other two, and stone arches at each end. The ribs are two-hinged, braced, crescent shaped with chords curved to a circle and the whole framing contains 2,000 tons of steel. The **Mainz railroad bridge** over the Rhine, similar to those at Trarbach, Magdeburg and Worms, has three river spans, with arch trusses, the ends of which are tied together with members under the floor. It crosses two arms of the Rhine and an island, having three spans over one channel and two over the other, with six suspended deck trusses of 130 feet on metal towers between the channels. It has provision for two tracks and two foot walks, and was completed in 1904 at a cost of $1,300,000. An arched truss bridge of the Bonn type on the Indo-China Railway

over the Song-Ma river, has a single three-hinge arch of 532 feet, with trusses 33 feet apart and suspended floor. The 1,200 tons of metal was erected on the cantilever method, with the assistance of a cableway.

397. The highest bridge in America crosses the **Rio Grande in Costa Rica,** 26 miles from San Jose, with its deck 340 feet above water (Fig. 260). It carries a single line of narrow-gage (3½-foot) railroad over a 448-foot, two-hinged, spandrel-braced cantilever arch, with 118-foot end spans. The main ribs are 16 feet apart at the center and batter out two inches per foot to 40 feet apart at the shoes. It was erected in 1902, as a cantilever, with the assistance of a 900-foot cable-

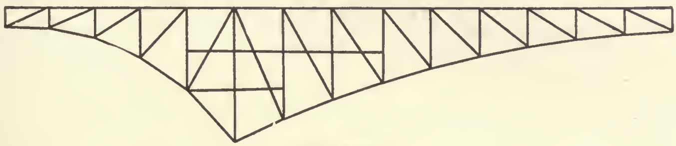


Fig. 260.

way with a 2½-inch rope, and contains 932 tons of steel. The connection of the lower chord of the suspended span to the cantilever, was made with bolts in slotted holes. Two other railroad arches were completed during the same year at New York City, and near Birmingham, Ohio. The first is the Rapid Transit Railway viaduct between 125th and 133rd Streets, which contains a span of 168½ feet, with two-hinge parabolic arch ribs 6 feet deep at the center, one end being 5 feet higher than the other, but the same number of different length panels are used on each side of the center. The other is the Vermilion river bridge at Birmingham, with twin deck spans carrying the Cleveland and Southwestern Traction line over a picturesque valley. It has a much better appearance than an ordinary truss, and the type is suitable where water and other natural conditions will permit. A very much heavier three-hinged arch over the **Menominee river**

south of Iron Mountain, Mich., has two lines of trusses in vertical planes 22 feet apart, with the center hinge midway between the upper and lower chords, and the panel points of the lower chord on a hyperbolic curve. The center pin was raised to avoid the large reversing stresses in the web, and the design is said to be lighter than one with a parabolic curve. It was proportioned for Cooper's E 50 engines, and a train load of 7,000 pounds per foot, for iron ore traffic. The weight of steel in the arch span is 240 tons and in the approaches, 75 tons more. It replaced a deck Pratt truss span 255 feet long, built in 1885, which was too light for the loads.

398. A new departure in American arch design was instituted in the building of the highway bridge over the **Connecticut river at Bellows Falls** (1905) between Rockingham, Vt., and North Walpole, N. H. (Fig. 261), with a span of 540 feet, the longest in America. It crosses the river just above the

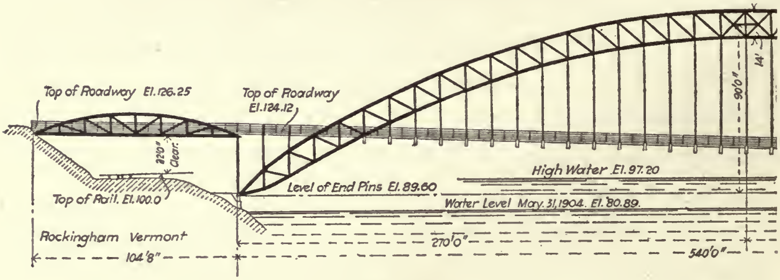


Fig. 261.

railroad bridge and the dam, which adjoins the entrance to the canal. A single span was adopted because of the canal company's objection to piers or other obstruction in the river. The parabolic ribs have parallel chords 14 feet apart, with the floor suspended from 33 panels, on a grade of 3.3 per cent ascending to the Rockingham side, where the shore road is crossed by a through bowstring span of 104 feet. It was designed by J. R. Worcester, contains 450 tons of steel, and

cost $47,000. An arch which is proportionately much heavier than the last, crosses the summit of **Croton dam,** where it was first intended to place a masonry arch. It has two solid plate girder ribs 36 inches deep at the crown, and 42 at the shoes, supporting the spandrel columns, and a floor with solid pavement. The balustrade has a solid plate without openings, and the face below the cornice is ornamented with spandrel arches. It was designed by Albert Lucius, and is very heavy, containing 350 tons of steel. The Croton river arch near the dam has a shorter span of 159 feet without hinges. Another open web arch is the Rio Fiscal bridge (1906) on the Guatemala Railway in Central America, which was designed by V. G. Bogue and erected cantilever similar to those at Niagara. Heavy arch bridges were built at Washington, Pittsburg and Boston in 1906 and 1907, which show clearly the tendency towards a better degree of **bridge architecture** in American cities. The first of these is the **Anacosta bridge** over the Potomac river at 11th Street, Washington, D. C., containing six fixed low level arch spans and a central double bascule draw, the clear length between face of abutments being 1,000 feet. This was under the direction of the United States government and from designs by W. J. Douglas, government engineer. Each of the fixed spans has six three-hinged plate girder arch ribs, 4½ feet deep, and a deck 48 feet wide, with asphalt and buckle plate floor, and two lines of railway. The weight of the draw span and machinery is 380 tons, and the total weight of metal in the bridge is 1,815 tons. Another fine arch bridge in Pittsburg, known as the **Oakland bridge** (1907), crosses the Pittsburg Junction railroad tracks and the ravine separating Oakland from Schenley Park (Fig. 262). The arch is 440 feet long with 30 and 40-foot end spans and a total length of 800 feet between abutments. The road is paved with asphalt and the walks with

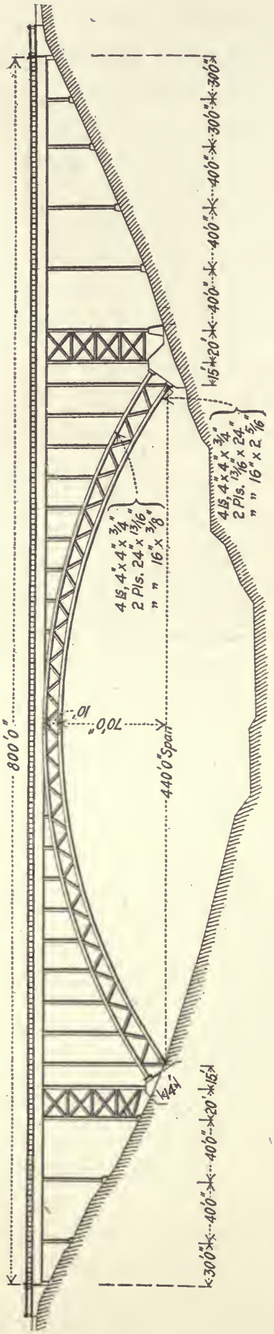


Fig. 262.

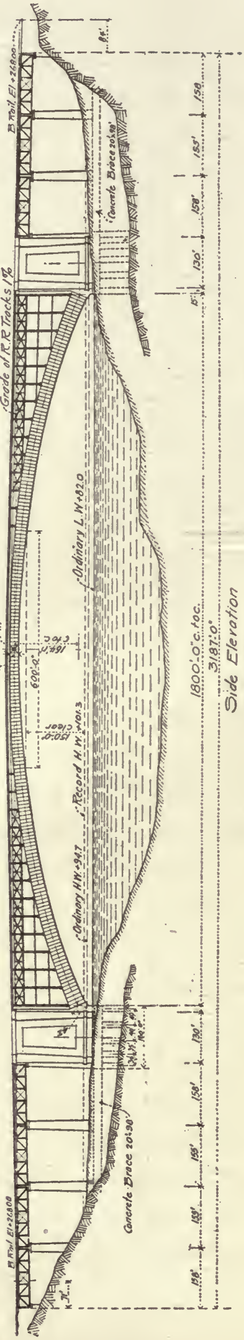


Fig. 268.

granolithic on buckle plates. The ribs are curved lattice girders without hinges, 10 feet deep at the center, increasing to 14 feet at the springs. It was designed by Willis Whited and cost $138,000, equal to $4.50 per square foot of deck.

399. The **new bridge at Cambridge** occupied more time in preliminaries than any other in America. The commission having it in charge prepared not less than thirty-seven different designs and made special trips to Europe before evolving the accepted plan. It crosses the Charles river on the site of the old West Boston bridge on eleven steel arch spans from 101 to 188 feet long, and a deck 105 feet wide between railings, the distance between abutment faces being 1,768 feet. Each span has twelve steel plate girder ribs supporting four lines of car track, two highways and two foot walks. It was constructed under the direction of William Jackson, city engineer, and Edmund Wheelwright, architect, at a cost of $2,500,000 and opened in 1907. The **Fort Snelling bridge** over the Mississippi river near St. Paul (1909) has two spandrel-braced deck arch spans of 364 feet with a 105-foot deck span at each end. It has two lines of vertical trusses and was erected on false work under the direction of F. R. Shunk, at a cost of $250,000. It is quite similar in outline to the old Lake Street bridge at Minneapolis. A design and proposal was submitted for building it in reinforced concrete at a cost which did not exceed that of steel.

400. The first decade of the twentieth century witnessed the origin or rebuilding of several important bridges by English engineers. One of these over the Waverly railway station at Edinburgh (1900) has three spans with six vertical plate arch ribs in each, the outer spandrels being ornamented according to the usual European practice with cast iron fascia. It has granite paving on brick arches between rolled steel floor beams. The **bridge of Commerce** (1905) over the Meuse

at Liege, has twin flat arches, the ribs of which bear on the center pier and thrust against each other, like the Grand river bridge at Lansing, Mich. (1895), rather than against the pier. The road is 48 feet wide with solid pavement. The great **Zambesi river bridge** (1905) (Fig. 263), constructed under the direction of the Canadian engineer Sir Percival Girourard of Montreal, has a central arch of 500 feet similar to the railroad arch at Niagara, with approach lattice girders at each side, making a total length of 650 feet. The deck is 30 feet wide, planked over, and carries a single narrow-gage line of the Rhodesia Railway at a height of 420 feet above water. The bridge is situated about 700 yards be-

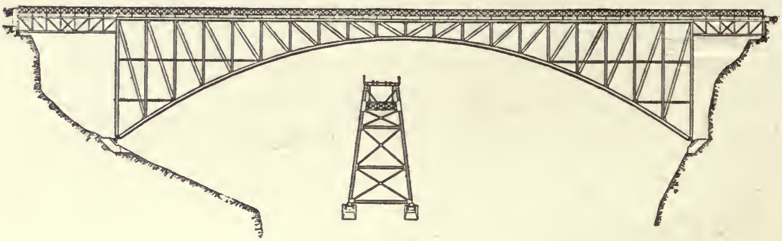


Fig. 263.

low the Zambesi Falls, giving travelers a view of the cataract. The two spandrel-braced arch ribs have their lower panel points on a parabolic curve, and are 27½ feet apart at top, battering out 1 in 8 to 53 feet at the base. The arches are riveted, and they thrust against solid basaltic walls. It was designed by G. A. Hobson and contains 1,650 tons of steel, which was exported from England, the total cost being $340,000.

401. Many of the **Thames river bridges** have been widened and rebuilt during the last century to meet the demands of increased travel, the two most recent ones being the Vauxhall and the Blackfriars. The temporary arch at **Vauxhall,** which was used for ten years, during the time of rebuilding, was removed in 1907, when the new one was com-

pleted. The first bridge for the site was designed by John Rennie, with stone arches, but the cost appeared excessive and the design was changed to cast iron, with James Walker as engineer, and it was completed in 1816, being the first iron bridge over the Thames. It continued as a toll bridge for sixty-three years and was then purchased by the city of London. The short spans with eight piers were found to be an obstruction to river travel, and it was rebuilt in 1898-1907 with only four piers and longer spans. Each span now has thirteen steel plate ribs 3 feet deep, with the floor supported on spandrel columns. It is ornamented with groups of sculp-

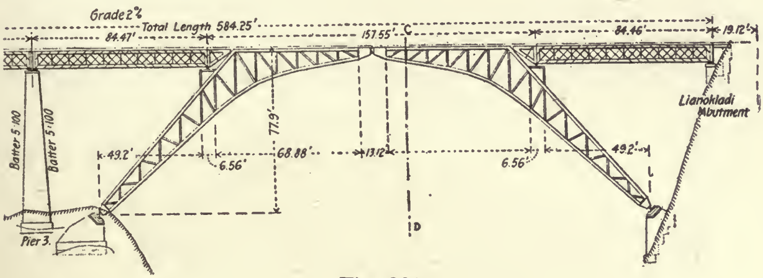


Fig. 264.

ture on the piers and is otherwise highly artistic. M. Fitz-maurice, engineer. The widening of **Blackfriars** bridge was begun in 1907 under the direction of Basil Mott and E. M. Wood, from the plans of Sir Benjamin Baker. The old bridge was completed in 1868 with nine spans of 70 to 100 feet. In widening it, the piers were extended on the up-stream end to carry three new lines of steel arch ribs, 10 feet apart, increasing the width to 105 feet, which makes it the widest one over the Thames.

An original type of three-hinged arch (Fig. 264) in the **Assopos viaduct** near Thermopylae, Greece, has a river span of 262 feet with four 86-foot lattice spans on stone piers at one side and a single span at the other end. The two arch

ribs lie in planes inclined to the vertical. It was designed by the French engineer Paul Bodin, and was under construction for thirteen months previous to August, 1906. The track is 330 feet above the valley, and the road enters mountain tunnels at each end of the viaduct. Four hundred and forty tons of steel and 505 cubic yards of masonry were used in its construction.

402. A somewhat similar three-hinged arch bridge (Fig. 265) has lately been completed (1909) over the Nami-Ti Gorge on the Yunnan Railway in China, the design of

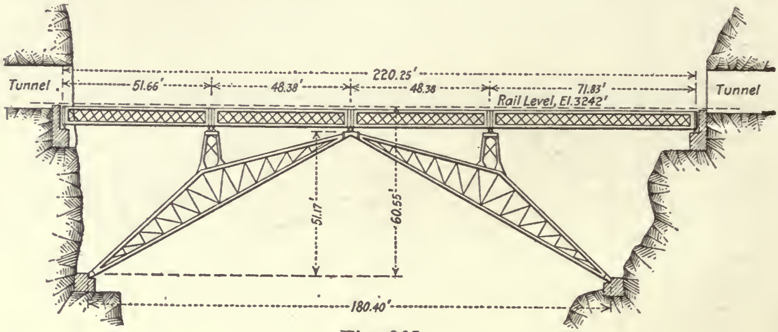


Fig. 265.

French engineers. The bridge is approached at each end through tunnels, the floor of which is 335 feet above the canyon. It has a span of 180 feet between side bearings and was tilted into place by means of ropes from the hillside above.

403. Preliminary designs and estimates were made in 1906 by H. G. Tyrrell for two large bridges of unusual proportions to carry a single line of railroad with heavy loads equal to Cooper's E 60 specification, over gorges in the Rocky Mountains. For one of these locations, nine alternate designs were made, the acceptable one being a single span braced steel arch of 750-foot span, with its deck 370 feet above the water (Fig. 266). For the other crossing, ten preliminary designs were considered, with single span of 475 to 600 feet (Fig.

267) and deck 420 feet above the valley. A double bridge with two roads, in the form of the letter X, was proposed (1910) to cross the Seine at Paris just above Pont Neuf, and the island, with arches meeting on a center pier.

404. Designs for two proposed large arch bridges over the East River at New York, have recently been made but

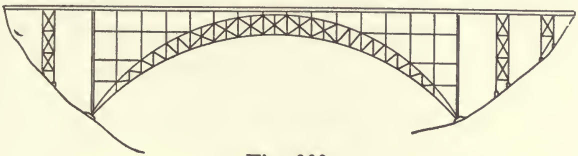


Fig. 266.

not yet executed—the Hudson Memorial bridge and another at Hell Gate. The first design for the **Hudson Memorial** bridge, to cross the Harlem near its junction with the Hudson, made by Messrs. Boller and Hodge, of New York, contemplates the use of a 400-foot steel span, but the design was

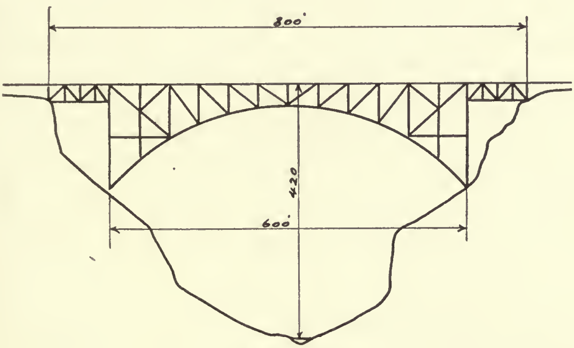


Fig. 267.

rejected by the Municipal Art Commission of New York because no steel structure was considered suitable for a great memorial. The plan showed three 80-foot semi-circular approach arches at the south end and five at the north, and massive piers with interior chambers, the two principal piers extending above the deck as monumental features. The ma-

sonry was proposed in either stone or concrete or a combination of both. The central span is shown with two pairs of three-hinged steel arches supporting a roadway 150 feet above the water, the total cost of structure, including the arches over the roadway and other decorative features, would not exceed $2,500,000. Another design for the Hudson Memorial bridge contains a central arch 825 feet in length, framed with two pairs of three-hinged arch ribs carrying a roadway 100 feet in width and 170 feet above the water. The whole length of 2,500 feet included seven masonry approach spans of 90 feet and two through the main abutments with spans of 65 feet, and a clear height of 120 feet. A statue of Hudson was intended to stand on a massive pedestal in a plaza at the southern end of the bridge. A design for one of the largest steel arches ever projected has recently been made by Gustav Lindenthal, with a clear span of 1,000 feet and road 140 feet above the water, to carry four lines of railroad over the East river at **Hell Gate,** New York. The project includes about three miles of viaduct, requiring 80,000 tons of steel. The position of the central span was emphasized by end towers 200 feet high, but this feature did not meet with the approval of the Municipal Art Commission. A street bridge over the Weser at Nienburg is typical of many recent ones in Europe. The Kremlin Palace bridge at Moscow, with two river piers, has a heavy balustrade extending out of the key walls.

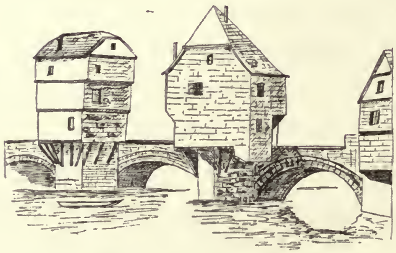
405. The largest metal arch bridge ever projected was one proposed in May, 1910, by Charles Worthington, for crossing the **St. Lawrence** river at **Quebec,** Canada, with a single span of 1,800 feet (Fig. 268). His plan shows a deck 88 feet wide with two 23-foot carriageways and two lines of railway, all supported on four rectangular steel voussoir arch ribs, 9 feet wide and varying in depth from 21 feet at the center to 42 feet at the springs, with a rise of 164 feet. The

essential structural parts of the bridge would be accessible for inspection and painting, and not buried in masonry, as with suspension and cantilever bridges. The voussoirs are shown in 9-foot lengths interlocking, built up of nickel steel plates and angles with interior bracing, and a sectional area of 27 square feet at the crown and 53 square feet at the springs. In determining the sectional area of the ribs, a compressive unit of 28,000 pounds per square inch was adopted, but if a smaller unit of 24,000 pounds were used, the cost of the bridge would be increased by about $500,000. Mr. Worthington proposes to erect the arches by suspending the voussoirs from cables, and when all are approximately in place, lowering them to their bearing. The abutments are shown 130 feet thick and the arch thrust on them is partly resisted by concrete struts 98 feet wide and 20 feet deep, extending back 800 feet to the cliffs. At one end are four approach truss spans of 155 feet on stone piers, and three similar ones at the other end. The estimated weight of the span is 36,000 tons, of which 22,500 tons is the weight of ribs and bracing. Several features of the design are patented by the originator, who reports that the bridge would compare favorably in cost with a suspension or cantilever.

A list of iron and steel arches with spans of 400 feet or more, in the order of their length, is given in the following table:

Name.	Date.	Span.
Niagara-Clifton	1898	840
Viaur	1898	721
Bonn	1898	668
Dusseldorf	1898	595
Oporto-Luiz I.	1885	566
Mungsten	1897	557
Niagara	1897	550

Garabit	1885	541
Bellows Falls....................	1905	540
Levensau	1893	533
Oporto-Pia Maria...............	1877	525
St. Louis.........................	1874	520
Grunenthal	1892	513
Washington	1889	510
Zambesi	1906	500
Paderno	1889	492
Austerlitz	1905	459
Minneapolis	1889	456
Costa Rica......................	1902	448
Magdeburg	1900	443
Pittsburg	1907	440
Rochester	1890	416
Richmond, Ind.	1886	400



CHAPTER XV.

TRESTLES AND VIADUCTS.

406. A distinction is made in these pages between trestles and viaducts, the former term referring to those structures which support a deck on numerous bents, either separate or braced together in pairs, while the term "viaducts" refers to bridges in which a series of longer spans are borne on individual towers composed of two or more bents braced together. Trestles are essentially an American type and are not used generally by the engineers of other countries.

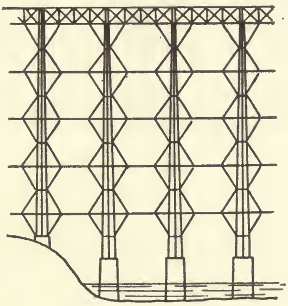


Fig. 269.

Timber Trestles.

407. Timber trestles have been used ever since Caesar built his bridge over the Rhine, A. D. 55, but came into general use after the beginning of railroad building in 1830. Among the first were a number for the Little Schuylkill and Susquehanna Railway, designed by James F. Smith in 1840, with heights of 30 to 130 feet. The most notable of the early ones was the **old Portage viaduct** (Fig. 269) over the Gene-

see river (1852), carrying one track of the Erie Railroad at a height of 234 feet above the water. It was 876 feet long with two lines of Howe truss 14 feet deep on timber towers. Each tower was composed of three bents braced together, and united with longitudinal girths at intervals of 40 feet vertically. The towers were spaced 50 feet apart on centers, and had a maximum height of 190 feet on stone piers 30 feet high. The timber bents were 25 feet wide on top, sloping out to 75 feet at the bottom. This trestle, designed in 1851 by Silas Seymour and completed the following year after eighteen months' work, cost $140,000. It contained 1,600 feet of timber, 60 tons of iron and 9,200 cubic yards of masonry,

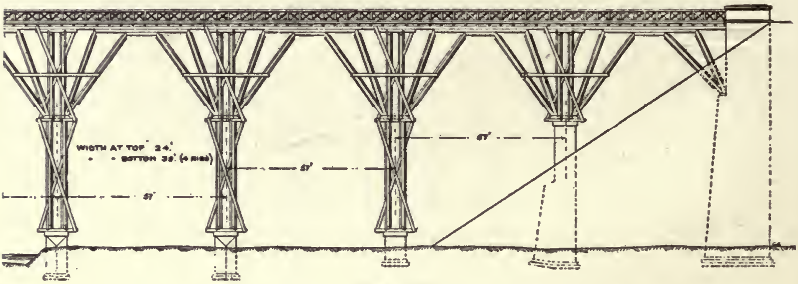


Fig. 270.

and was the boldest timber trestle ever built. Being burned in 1875, it was immediately replaced by one of metal. Following the building of the Portage bridge, the use of timber trestles began in England. One over the Dearness river (1857), by T. E. Harrison (Fig. 270), for the York, Newcastle and Berwick Railroad, 83 feet high with eight spans of 57 feet, had bents on masonry bases spreading out at the top into fan-shape like those used by Brunel on lines in the West of England, which were not expensive. This type was not the one generally used by Mr. Harrison, but it remained in use till 1900, when it was replaced by a brick arch viaduct. Another similar timber trestle on the Cornish branch of the

Great Western Railway of England had a series of spans, with masonry piers about 60 feet apart and 70 feet high, each pier being surmounted by four bents spread out in fan shape to support the deck, the height of which was 100 feet or more above the ground. A bridge like this, but lower, crosses the water at Victoria, British Columbia. Few of these timber viaducts now remain in England, for most of them have been replaced by brick arches. Temporary wooden trestles have been extensively used for military purposes, as those in the civil war of 1863. A notable one is the Potomac trestle, 80 feet high and 400 feet long, built by the United States army in nine days under the direction of Herman Haupt, and made mostly of round timber. The rapid building and development of American railways, especially in the West, where timber is plentiful, has brought into existence a large number of timber trestles too numerous to describe, and a few only can be mentioned. The **Marent Gulch** bridge on the Northern Pacific Railway, ten miles west of Missoula, Montana, was designed in 1883 by C. C. Schneider as a timber trestle with eight braced piers 226 feet high, consisting of double bents 20 feet apart supporting spans of 50 feet. Longitudinally the bents were vertical, but transversely they were 10 feet apart at the top, sloping out two inches per foot to the foundations. They supported wooden Howe trusses 10 feet deep and 10 feet apart, carrying a single track. The longitudinal tower bracing consisted of 6 by 10-inch timber and horizontal tie rods 16 feet apart, but the transverse bracing was more complex. The wooden trestle was replaced a year or two later by a steel one with 116-foot truss spans between towers 140 feet apart on centers. Some very large timber trestles were used in the building of the Canadian Pacific Railway through the Rocky Mountains in 1885, one at **Mountain Creek,** designed by W. A. Doane, having a length of

1,070 feet and a height of 150 feet. Bents were spaced 15 feet apart up to 75 feet in height, and 30 feet apart for greater heights, with a central 150-foot span over the river on triple bent, timber towers at each side. The whole bridge cost $67,300. The center span was afterwards replaced by steel on double steel towers, and much of the timber trestle at the ends filled in with earth by means of a hydraulic jet. The Bellevue trestle on the Algoma Central Railway, 1,500 feet long and 169 feet high, is one of the largest in that region. The **Two Medicine bridge** (1890) on the St. Paul, Minneapolis and Manitoba Railway was 211 feet high and 750 feet long for single track, and contained one span of 120 feet and four of 40 feet, in addition to the regular 16-foot spans toward the ends. The timber pier at each side of the larger span had triple bents braced together. A trestle on the Esquimault and Nanaimo Railway (1890) over Niagara Canyon on Vancouver Island, 14 miles north of Victoria, is 585 feet long on a 10-degree curve. The bents, which are 120 feet high, stand on a 60-foot rock fill, making the deck 195 feet above the water. Other notable ones in the West are those on the Pacific extension of the Chicago, Milwaukee and St. Paul Railroad (1908), which are joined together with spikes, the only bolts being those through the guard rails. The largest ones are those at Mine Creek, 155 feet high; Change Creek, 160 feet high, and Heason Creek, 190 feet high. Erection was facilitated by the use of an aerial cableway. A similar electric railway trestle over a ravine near Boone, Iowa, is 165 feet high and 800 feet long, with forty-eight bays in fourten stories. Among the numerous timber trestles in the South, in a region of abundant timber, are those for the North Alabama Railway, one of which, at New Found Creek, is 684 feet long and 115 feet high, with uniform 12-foot bent spacing, and continuous longitudinal girths. Alternate pairs of

bents were braced together with diagonals. Several timber trestles of great length have been used in recent years to carry lines of railroad over swamps and shallow water, among which are those at Lake Pontchartrain, near New Orleans, La.; Great Salt Lake, Utah; and Albermarle Sound. The **Pontchartrain** trestles crosses six miles of lake and 16 miles of swamp on pile bents 15 feet apart, all of which, excepting 30,000 feet, was afterwards filled in. It included two draw spans of 250 feet and was the longest bridge of any kind in existence. The later one on the Lucin Cut Off over **Great Salt Lake** has a gravel deck and is now (1910) being raised above flood level. A similar one of the Norfolk and Southern Railway over **Albemarle Sound,** where the water is 21 feet deep, has an open deck and a length of 26,668 feet, with bents 12½ feet apart. Five plate girders, 50 feet long, on pile piers at occasional intervals, afford clear openings of 35 feet for the passage of motor boats, and one rolling lift span gives a clear space of 140 feet for ships with masts, while a 94-foot plate girder swing span provides double passage ways for other craft. Timber trestles in other countries do not correspond exactly with American practice, as is illustrated by one at Manawater, New Zealand (1890), 463 feet long and 68 feet high, which has bents 29½ feet apart and continuous longitudinal bracing in all bays, with additional deck bracing in the upper story. In 1895 the Government of Ceylon proposed connecting that island with the mainland by means of a railroad over Polk's Straits, containing a bridge forty-one miles long. The water in the Straits is usually not over 6 feet deep.

Steel Trestles.

408. The first iron trestle (Fig. 271) was on the Stockton and Darlington Railroad over the Gaunless river near West

Auckland, erected by George Stephenson, 1823. The first change of type from single disconnected piers like those at Portage was in the Carey Street trestle (Fig. 272) at

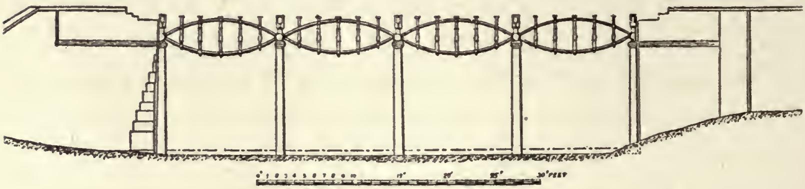


Fig. 271.

Baltimore, designed by Wendell Bollman (1851), the same year in which Mr. Seymour designed the Portage bridge. The framing was all wood and the bents were connected by continuous lines of timber girths, all panels having

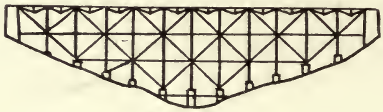


Fig. 272.

diagonal longitudinal iron rods connecting to pins in the shoe castings under the columns. This was the first time that bents were braced together with iron rods. The first all-iron trestles in America were on the Baltimore and Ohio Railroad,

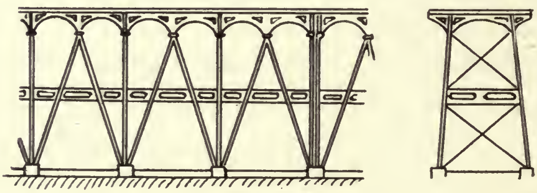


Fig. 273.

the work of Albert Fink in 1853. They were the Tray Run and the Buckeye viaducts (Fig. 273) over Cheat river, which were entirely of cast iron, excepting the bracing rods. The first of these was 58 feet high and 445 feet long, while the

second was 46 feet high and 350 feet long, both having 28-foot decks. They were founded on continuous masonry walls, with expansion points at intervals of 125 feet. The intention at first was to build the walls up to grade, but cast iron trestles were used instead. The Tray Run viaduct was replaced in 1887 by a modern steel trestle and in 1885 the Buckeye viaduct was removed and side walls built up. Columns had a slight transverse batter, and column bases were tied together with rods.

409. In 1853 a design was made by Liddell and Gordon, engineers, for a viaduct (Fig. 274) differing from those used in America, to support two tracks of the Great Western Rail-

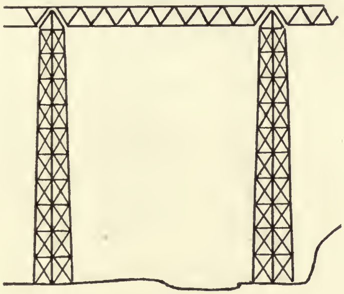


Fig. 274.

way over a mountain gorge and the Ebbw valley, near the village of **Crumlin,** in Monmouthshire, South Wales. The bridge is divided by a natural ridge into two parts, one of which has three spans and the other seven spans of 150 feet each, having a total length of 1,800 feet and a maximum height of 210 feet above the valley. Four lines of Warren wrought iron lattice trusses 14½ feet deep and 9 feet apart in pairs are supported on towers made of fourteen lines of hollow cast iron columns, 12-inch diameter, with 1-inch metal, in 17-foot lengths The columns taper in towards the top, giving the piers their greatest width at the base. It was

completed in 1857 by T. W. Kennard, contractor, at a cost of \$195,000, and was the first iron viaduct with independent towers. The design was original and it has served as a pattern for many later ones in other countries.

410. In 1856-57 the American engineer, F. C. Lowthorp, designed and built an iron viaduct (Fig. 275) over Jordan Creek on the Catasauqua and Fogelsville Railway with nine spans of 100 feet and two of 110 feet, with a total length of 1,122 feet. The towers were 89 feet high, made of clusters of cast iron columns assembled in double piers on large masonry bases, and braced together with adjustable wrought

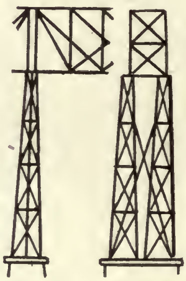


Fig. 275.

iron rods. The bridge continued in use till 1889, when it was replaced by a heavier one.

411. A new system of trestle building was begun in England about 1860 by Sir Thomas Bouch, who used short bays with bents on small individual piers, instead of cluster towers on large masonry foundations. The cost of the Crumlin type appeared to be excessive, and one designed by Mr. Bouch at **Belah** (Fig. 276), with a height of 180 feet for double track, had towers composed of double bents, 15 feet apart, braced together, supporting 45 intermediate spans similar in outline to the latest type in America. The bents, with three lines of cast iron columns, were battered one per cent longitudinally and one inch per foot transversely, and the 12-inch diameter

hollow columns were connected by cast iron struts and wrought iron diagonal rods with cotters. The deck was laid on three lines of continuous lattice trusses 11 feet apart, the continuity adding greatly to its rigidity. The whole viaduct was completed in the short space of four months and was

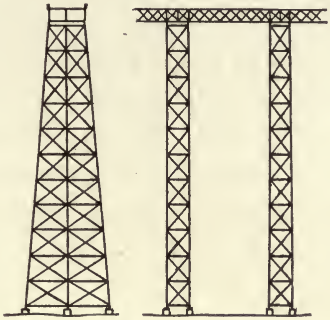


Fig. 276.

hastened to the utmost, as other construction was dependent on its completion. In comparing the cost of this type with the cost of brick viaducts, Mr. Bouch found the brick ones to cost 25 per cent more than iron. The lattice girders of this viaduct were strengthened in 1898 to carry the increased

Fig. 277.

loads from ore traffic. When building the Grand Trunk Railway of Canada about 1860, English and Canadian engineers made general use of plate girders on high masonry piers like that over the **Humber at Weston,** Ontario. This bridge (Fig. 277) is 650 feet long and 70 feet high, with nine

spans 72 feet long. Two lines of girders 4 feet 4 inches deep support 8 by 12-inch ties 18 feet long and the deck was guarded on each side by two lines of light chain in iron railing posts. The lower 12 feet of the piers are stone, but above they are faced with brick. The piers are 7 feet thick and 15 feet wide at top and are capped with stone with cast iron bed plates under the girders. Bridges of simlar type were much used in England and Scotland, an example being the Daff viaduct on the Wemyss Bay Railway near Iverkip, Scotland, which is 360 feet long, and 89 feet high.

412. **European practice,** especially that in continental Europe, differs greatly in viaduct design from that in America, and is well illustrated by structures at Fribourg, Tarente, Busseau, Assenheim and Angelroda. The **Saone viaduct at Fribourg,** Switzerland (1863), has 157- foot metal towers on stone piers 93 feet high and 158 feet apart on centers, the total height being 250 feet. The towers have twelve lines of 13-inch columns, the outer ones having a slope in four directions, and being united by lattice bracing. The bridge has two tracks on four lines of trusses and it was designed by Mathieu, the metal costing $355,000, while the whole bridge cost $480,000, or $2.16 per square foot of profile area. The **Castelleneta viaduct** near Tarente, the highest metal bridge in Italy, has four spans, with a deck 270 feet above water, supported on three metal towers 177 feet apart, founded on masonry bases (Fig. 282). The lattice girders are 14.8 feet apart and the towers, with four lines of columns, slope out in four planes to the foundations. The lattice bracing is similar to that on the Fribourg viaduct. Two other similar ones are the Creuse and the La Cere viaducts, both of which were designed by Nordling. The **Creuse railroad viaduct** (1865), 185 feet high, is located at Busseau, and is 940 feet long, similar to the Fribourg viaduct. It has metal towers standing

on high masonry piers and cost $255 per lineal foot, or $2.20 per square foot of vertical profile. **La Cere viaduct** (1866), on the Orleans railway, is 175 feet high and 775 feet long and cost $138 per lineal foot, or $1.58 per square foot of profile area. The Nidda viaduct at Assenheim has a series of nine deck spans with curved bottom chords. The trusses have pin bearings on the piers, which were made wide enough to support a second track (Fig. 284). The Thalubergang viaduct at Angelroda, for single-track railroad, has three deck spans of 100 feet on towers with trusses 11.2 feet deep and 9.8 feet apart, and walks at each side on brackets.

413. With the building of the **Bulloch Penn** viaduct in 1868 on the Cincinnati and Louisville Railway, a new kind of

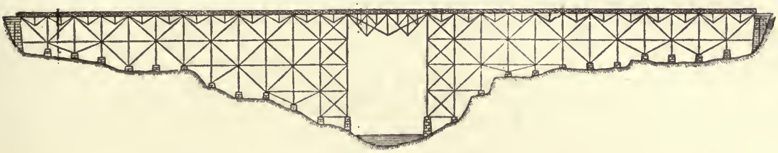


Fig. 278.

trestle was started in America with separate bents on individual piers. In this respect it was similar to those in England by Sir Thomas Bouch prior to 1861. It was 470 feet long and 60 feet high, with separate bents at the ends and braced towers in the middle, and was planned by Frederick H. Smith in 1867 and manufactured by Smith and Latrobe in 1868, who made five similar ones about the same time. These were the first of their kind in America and the beginning of modern iron trestle building there. The **Lyon Brook** viaduct (Fig. 278) on the New York, Oswego and Midland Railway (1869) was the highest of the early metal trestles in America, with its deck 162 feet above water. The regular wrought iron bents were 30 feet apart and were united with continuous lines of wood girth, wood being used instead of

iron to avoid trouble from expansion. In all longitudinal bays were diagonal wrought iron tie rods. The brook was crossed by a 100-foot truss span 20 feet deep, supported on a pair of iron bents at each end, united with a system of iron bracing, iron struts being used in these two towers instead of the regular wooden ones. Columns were battered one in eight transversely and they stood in cast iron foot boxes on isolated pedestals. The whole trestle contained twenty-four spans of 30 feet, in addition to the center span, and cost $49,000. Other similar ones built by Smith and Latrobe about the same time were the Arequipa viaduct in South America, 1,500 feet long and 55 feet high; the Running Water viaduct, 692 feet long and 115 feet high; Clark Run viaduct, 460 feet long; Sidney Center viaduct, 1,500 feet long and 100 feet

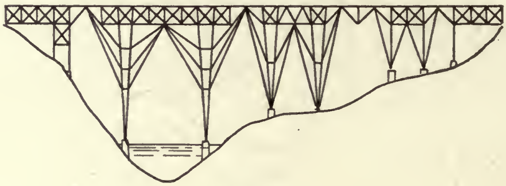


Fig. 279.

high, and the St. Charles bridge trestle, 4,318 feet long. The Rapallo viaduct (1869), from the shops of the Phoenix Bridge Company, for the New Haven, Middletown and Willimantic Railway, with forty-six spans of 30 feet and a height of 30 to 60 feet, had towers with three bents braced together, and bracing omitted in every third panel. In the same year, 1869, a proposed design by T. C. Clark for the Blackwell's Island bridge at New York, contained approach trestle with alternate spans of 25 and 50 feet, and bents braced together to form towers. In the following year Charles Shaler Smith designed and built trestles similar to those by Mr. Clark, which were probably the first ones of the modern type actually erected in America. In 1870 Charles Bender was granted

patents on a form of trestle (Fig. 279) with supporting members spreading out in fan-shape from the piers, similar to the wood trestles used by T. E. Harrison and others in England previous to 1857, but none of Mr. Bender's trestles were ever built. In the following year Edward Serrell, of New York, patented a form of trestle with the center bent of triplicate towers rigidly fixed to the piers, and the base of the other two bents in cast iron expansion shoes. The **St. Charles bridge** over the Mississippi, first erected in 1871, with Fink trusses, was rebuilt (1880-85) with double intersection Whipple trusses, and a long trestle approach with Phoenix columns,

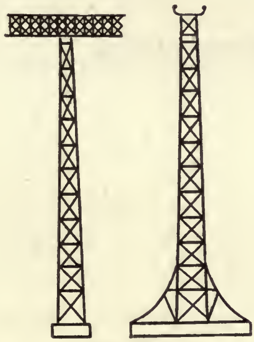


Fig. 280.

designed for loads equivalent to Cooper's E. 25. It remained in its original condition until 1910, when the trestle was strengthened by encasing the columns and struts in concrete, and made secure for E. 50 loading, work being done in three months, from May to August, at a cost of $17,000.

414. Four viaducts on the Commentry-Gannat line in France have lattice girders on metal towers with spread bases and four lines of columns in each tower. **La Bouble viaduct** (Fig. 280) is 216 feet high with 160-foot spans on towers which batter 1 in 40 longitudinally and 1 in 28 transversely. The trusses and columns are 13.1 feet apart at top and the towers are divided into vertical bays of 16½ feet. It is 1,300 feet

long, and cost $1.10 per square foot of vertical profile. The **Bellon viaduct**, on the same line, is 160 feet high with lattice girders 15 feet deep and 131 feet long, spaced 13.1 feet apart on similar towers, with longitudinal widths of 9.8 feet at top and 14 feet at the bottom. The steel work terminates at the ends on masonry arches, and the whole viaduct cost $1.25 per square foot of area between base of rail and bottom of valley. Others on the same line are the Neuvial and the Sioule viaducts of 1871, both for single track. The towers of these four viaducts differ from those previously designed by Nordling at Creuse and La Cere, by having only four columns in each

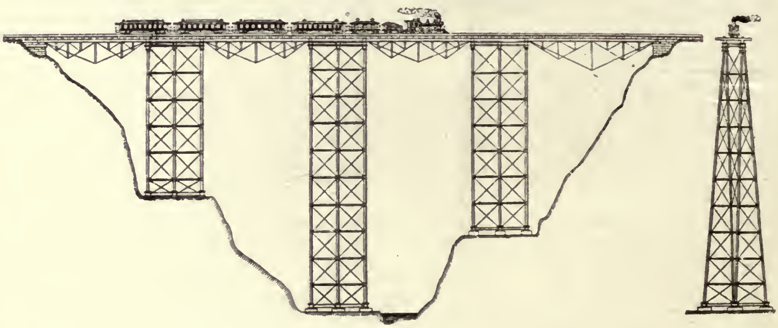


Fig. 281.

tower instead of many. Two others of 1873 are those at Olter over the Aar, and St. Gall over the Sitter.

415. The **Verrugas** viaduct (Fig. 281) on the Lima and Oroya railroad over a gorge in the Cordilleras, 50 miles from Lima in Peru, is 575 feet long and 256 feet high with trusses supported on three triplicate bent towers, with bents 25 feet apart. The deck was carried on four Fink truss spans, three of 110 feet and one of 125 feet. Towers were 50 feet long and 15 feet wide on top, and contained wrought iron columns battered transversely one inch per foot with cast iron joint blocks, the height of the three towers being 145, 252 and 178 feet respectively. It was designed by C. H. Latrobe and built

by the Baltimore Bridge Company in 1872, the manufacture occupying 88 days and the erection 3½ months. In the five previous years, the same company built about three lineal miles of iron railroad trestle. The Verrugas viaduct was the first large one of wrought iron, with independent braced piers. It collapsed in 1889 and was replaced by a steel three-

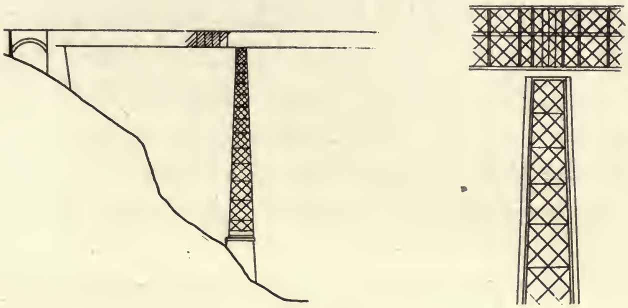


Fig. 282.

span cantilever. The Cincinnati Southern Railroad was one of the largest users of iron trestles, and a number of important ones were built on that line from designs by G. Bouscaren, its chief engineer. He considered that continuous lines of longitudinal bracing should run from the top of bents to the bottom of the adjoining ones, and to secure this he

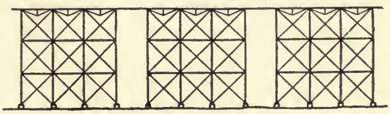


Fig. 283.

continued the longitudinal diagonals through several adjoining bays. The Horse Shoe Run and Cumberland Railroad viaducts (Fig. 283) were of this form, the former being 89 feet high and 900 feet long, and the latter 100 feet high with 35-foot bays and Fink trussing. Fishing Creek viaduct, by Bouscaren (1876), was the first with double towers of the modern type, with towers and intermediate spans of the same

length. It was 79 feet high with 20-foot spans and short Fink trusses. In 1878 Mr. Bouscaren first proportioned the length of the intermediate spans to their height, using this arrangement for McKees Branch viaduct, which was 128 feet high at the center. In 1881 he first made use of hinged bents bearing on pins at the shoes. Viaducts in Norway with rocker bents appeared about the same time or a little earlier, and were used at Lysedalen in 1877 and at Thomter over the Solbergthal in 1881, both of which have 65-foot deck spans on rocker bents 100 feet high. The Solbergthal viaduct has nine spans of 38 to 65 feet with parallel chord trusses, while the other has horizontal upper chords and curved lower ones. In both cases the bents have a transverse batter and the columns

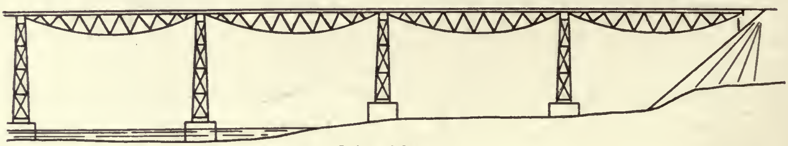


Fig. 284.

taper longitudinally, being wider at the middle than at the ends. Another railroad viaduct with rocker bents is that over the Oschutzbach valley, near Weida (1884), with three lattice trusses 118 feet long and a platform 66 feet above the valley.

416. **The modern type** of railroad trestle reached its present stage of development with the building of the first iron **Portage bridge** in 1875 and has not greatly changed since that time. The new Portage bridge on the Erie Railroad replaced the timber one of 1852 and was designed by George S. Morrison, bridge engineer for that company. The old wooden structure had uniform spans of 50 feet, but when renewing it alternate spans of 50 and 100 feet were used over the highest part, and some of the foundation piers discarded. It contained ten spans of 50 feet, two of 100 feet and one of 118

feet with six towers, the highest being 203 feet. The towers were made heavy and wide enough for two tracks, though only one track was laid. The intention was to add two more lines of intermediate trusses for the second track, which, however, was never required. Trusses were pin connected and 20 feet apart, with track on 8 by 16-inch ties, 22 feet long and 14 inches apart, resting on the top chords, and the bridge contained 655 tons of structural steel, 14 tons of bolts and 130,000 feet of timber. It was rebuilt again in 1903 (Fig. 285) and the deck replaced by heavier single-track girders. Oak Orchard viaduct on the Rome, Watertown and Ogdensburg Railroad near Rochester, N. Y., with a height of 80 feet and a length of 690 feet, had twenty-three spans of 30 feet, with short Fink trusses 9 feet deep and 10 feet apart, and alternate pairs of bents braced together in towers. It was proportioned for a live load of 75 tons on each 50 feet, and contained 182 tons of steel.

417. The first **Kinzua viaduct** on the Bradford branch of the New York, Lake Erie and Western Railway (1882) was a light iron structure 302 feet high and 2,052 feet long, built by Clark, Reeves and Co. It contained twenty-one alternate apart for single track. The deck had an extreme width of 18 feet and the whole bridge contained 1,400 tons of iron. Bents had a transverse batter of two inches per foot, and alternate pairs of bents 38½ feet apart were united into towers. In order to use girders of the proper and yet different depths in the tower and intermediate spans with strong connection to the columns, the Ontario and Quebec Railway Company adopted in 1882 a form of girder for the intermediate spans with curved bottom chords, like those on their Rosedale viaduct over the Don at Toronto. The intermediate girders varied from the depth of the tower girders at the ends to their required economic depth in the middle. The Rosedale

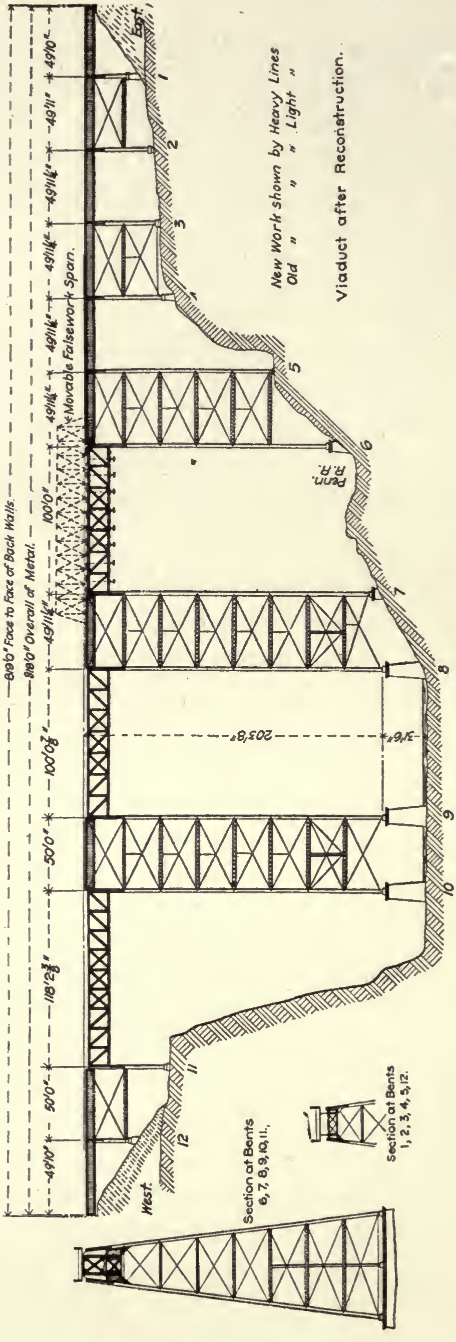


Fig. 285.

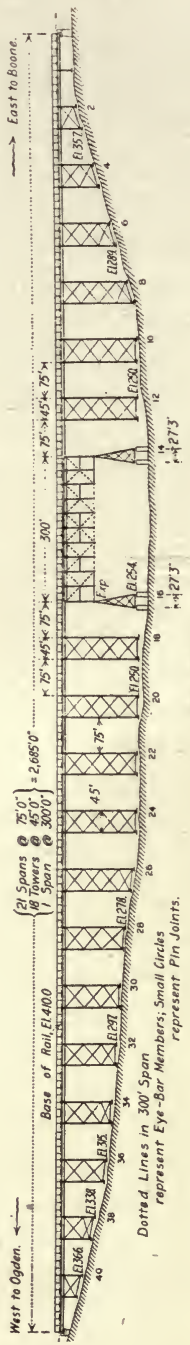


Fig. 288.

viaduct has 30 and 60-foot spans with girder depth of 2½ feet in the towers and 4½ feet in the other spans.

418. The Dowery Dell viaduct on the Halesowen branch of the Midland Railway is similar to others in England, with lattice girder spans on metal towers, each tower containing six lines of columns braced together. Another type in England differing from the Dowery Dell and from the Crumlin and later ones by Sir Thomas Bouch was designed in 1880 by J. Dixon for the Whitby and Loftus Railway. Several of this kind were built, among them the Staithes viaduct, 690 feet long and 150 feet high. The bents, which were 60 feet

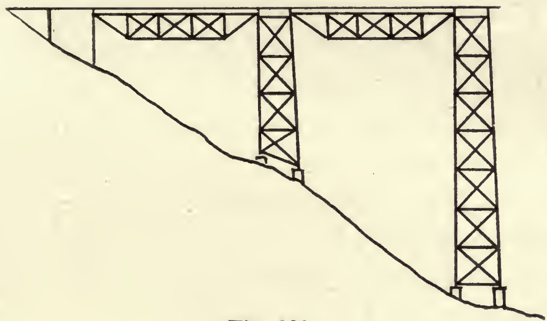


Fig. 286.

apart through the central part, consist of pairs of wrought iron cylinders filled with concrete and united with transverse bracing. The piers originally had no longitudinal connection below the deck, but were strengthened in 1883 under the direction of T. E. Harrison by the addition of two lines of longitudinal struts. The floor is carried in the 30-foot spans on plate girders, and in the 60-foot spans on lattice trusses continuous over the piers. This and similar viaducts were erected from the deck without false work by lowering pieces into position, as is done in the modern American practice.

419. The **Marent Gulch** viaduct in Montana on the Northern Pacific Railway, which, when first built in 1883, was of

timber, was renewed a year or two later in steel (Fig. 286), with five truss spans of 116 feet between towers 24 feet long at top, battering out longitudinally and transversely to the foundations. It is 200 feet high and 800 feet long, with two approach spans of 30 feet at each end. Trusses and columns are 20 feet apart transversely, with a system of stringers and floor beams. The piers contain 544 cubic yards of concrete and the superstructure 843 tons of steel, equal to 2,133 pounds per lineal foot, the complete cost being $178,000. It is one of the best proportioned and most satisfactory designs in America.

420. Two unusually large highway viaducts are those at St. Paul over the Mississippi, and at Cleveland over the Cuyahoga. One at St. Paul contains twenty-eight spans of 40 to 250 feet, the greatest under clearance being 129 feet. The viaduct portion has the bents of every fourth bay braced together, the remaining bents standing independently. A somewhat similar one at Cleveland, known as the Cleveland Central Viaduct (1888) has a length of 5,228 feet, with 40-foot road and two 8-foot sidewalks, 101 feet above the valley. It has 30-foot tower spans, with intermediate ones of 43 to 135 feet. The road had block pavement on pine plank, and the sidewalk three-inch pine, the whole containing 5,370 tons of steel and costing $675,000. The Loa, Malleco and Pecos viaducts (1888-92) are among the largest ever built. The **Loa in Bolivia** is 336 feet high, carrying a narrow (2½ feet) gage track of the Antofagasta Railroad. The **Malleco viaduct** in the southern part of Chili (1891) is 310 feet high, with multiple system lattice girders on four metal towers. It was designed by Aurilio Lasterria, and the metal was exported to Chili from France. The type is the prevailing continental one, with long spans between piers 225 feet apart. Other notable ones are the Souleuvre viaduct in France, 1,200 feet long and

247 feet high, and the Moldau viaduct in Bohemia, 886 feet long and 214 feet high. A railroad trestle in Mittweida valley near Schwarzenberg, Saxony (1889), has a series of trusses with curved bottom chords between braced towers, the floor above the towers being supported by a system of Fink trusses, above the tower bracing. It is said to be patterned after the American type, but the resemblance is not striking. The **Pecos viaduct** (1894) is one of the largest in America, and is unusual in having a pair of cantilevers with a clear span of 185 feet above the river, each cantilever being supported on a tower of regular outline. Other towers have 35-foot plate girders with lattice trusses in the intervening spans. It was proportioned for an assumed wind pressure of 50 pounds per square foot, and erected by sixty-seven men in eighty-seven days. The west end, 1,070 feet long, has an average height of 57 feet, and 600 feet of the east end an average height of 260 feet, with a total average through the whole length of 129 feet. The profile area between base of rail and top of piers is 280,000 square feet, and the whole viaduct cost $238,000, equal to $119 per lineal foot. Panther Creek viaduct (1893) on the Wilkesbarre and Eastern Railway, 154 feet high and 1,650 feet long, has alternate spans of 30 and 65-foot plate girders on towers with rigid bracing, and was erected in a period of six weeks. An unusual type of viaduct with only a single line of center columns having wide spread footings somewhat similar to parts of the New York City elevated railway, was erected at San Fernando Street, Los Angeles, in 1891. It was 1535 feet long and 26 feet high, and carried two lines of cable cars.

421. A movement towards better and more **artistic design** was started in 1896 by the construction of several viaducts in which due consideration was given to their appearance. Among these were highway viaducts near Cleveland, Ohio;

Knoxville, Tennessee; and Snodland, England. The one on Loraine Street near Cleveland, Ohio, over the **South Rocky river,** has nine spans on metal towers, with a street 32 feet wide, 130 feet above the valley. The trusses, with curved bottom chords, are without arch action, and their center depth is slightly less than ordinarily used for trusses with parallel chords. The towers, which are 18 feet long on top, have a batter of one-half inch per foot longitudinally and one inch per foot transversely. The framing is riveted and gussets or connection plates are curved and projecting brackets and railing are artistic. A brick pavement on buckle plates, with two lines of car tracks, constitute the floor. Towers were erected from below and the trusses assembled and connected on the ground and afterwards hoisted into place. The Osborn Company of Cleveland were engineers, and the finished cost of their work was $160,000. Another artistic design is the **Knoxville bridge** over the Tennessee river, an arched cantilever viaduct, with curved bottom chords on stone piers. It is 43 feet wide with a 30-foot paved roadway and two walks with a double line of street railway. It was designed by C. E. Fowler, with five main spans, each about 280 feet in length, and half spans at the ends. The **Snodland bridge over the Mersey,** England, is a long arched viaduct with nineteen spans of 120 feet and one of 240 feet, with a maximum under clearance of 95 feet above the water. The two lines of arch ribs have tubes for the bottom chords, 24 inches diameter in the shorter spans, and 36 inch for the longer one. The regular piers consist of steel tubes 3½ feet diameter, braced together, while the two adjoining the river are 6½ feet diameter and 60 feet high to the springs. The bridge has an 18-foot road and two walks on cantilever brackets, with a total width of 30 feet, and contains 1,600 tons of steel with an average cost of $33 per lineal foot of viaduct. H. Woodhousen engineer.

422. The rolling mills producing structural shapes were so crowded in 1899 that it was difficult to secure steel in any reasonable time, and when building the Grasshopper creek trestle on the Chicago and Eastern Illinois Railroad it was impracticable to wait for mill delivery, and other sections were substituted. The columns are composed of double channels with a beam between them, and the 25-foot tower spans have six lines of 24-inch beams at 100 pounds, three under each rail, while the 47½-foot intermediate spans have four 24-inch beams at 80 pounds trussed with double channels and a web system of 15-inch beams.

423. Trestles and viaducts have frequently been renewed because of the increased weight of locomotives and train loading, and several in America have thus been replaced, including those at Verrugas, Lyon Brook, Kinzua and Portage. **The rebuilding** of the Verrugas viaduct as a cantilever has previously been mentioned. The **Lyon Brook** trestle on the New York, Ontario and Western Railway originated in 1869, was rebuilt in 1894, with square towers, under E. Canfield, the new trestle being placed outside the old one, at a cost which was less than the cost of the original bridge. The Kinzua viaduct of 1882 continued in use for eighteen years, when it too was reconstructed (1900) for heavier loads, under the direction of C. R. Grimm. It contains twenty-one spans of 60 feet between double bent towers 38½ feet long with girders 6½ and 5 feet deep respectively, and all joints riveted. A feature of the reconstruction is the absence of transverse diagonals in the bents, which are strengthened by corner bracing at the cross struts. Girders are framed into the columns instead of resting on them, and expansion is provided for by sliding pockets or girder seats on the columns at occasional intervals.

424. Two of the largest viaducts ever made were pro-

duced in American shops in 1900, one for export to Burmah and the other for erection at Boone, Iowa. The **Gokteik viaduct** in Burmah (Fig. 287) is 2,260 feet long and 320 feet high, with fourteen single 40-foot towers and one double tower, supporting ten spans of 120 feet, and seven of 60 feet. Bents are 24½ feet wide at top, for double track, but girders for one track only were placed at first. Columns have a batter of 2½ inches per foot transversely, which is more than is usual on similar structures. To stiffen the deck laterally the top flange of truss, floorbeams and stringers are all at one level, and where they join are covered with 5/16-inch plates. It was built under the direction of Sir Arthur Rendel, engineer for the Burmah Railroad Company. The most favorable con-

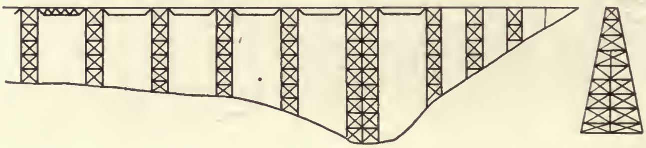


Fig. 287.

struction tender submitted by a European firm was $130 per ton for the steel, with completion in three years, while the American firm which was awarded the contract received $75 per ton for completion in one year. It was erected by the use of a traveler with a boom 150 feet long. The **Boone viaduct** (Fig. 288) on the Chicago and Northwestern Railway, over the Des Moines river, is 185 feet high with eighteen tower spans of 45 feet, and twenty-one intermediate spans of 75 feet, with a 300-foot span over the river, on special towers. It has four lines of plate girders with a uniform depth of 7 feet and is the longest double-track viaduct in the world. Towers have stiff diagonal bracing without horizontal struts, excepting at the bottom, and each column consists of two 20-inch beams and one 15-inch beam standing on cast iron shoes.

Girders have four angles in the upper flange and over the columns the girders are halved together, the lower half of one girder end forming a seat for the upper half of the adjoining one. Tracks are 13 feet apart on center and column legs 19½ feet apart at top, while the whole deck is 36 feet wide, protected at each side by strong iron railings. It was designed by George S. Morrison. Another large viaduct over the Des Moines river for the Mason City and Fort Dodge Railway, at Fort Dodge, Iowa, is 138 feet high with 38-foot towers and 75-foot spans, and four spans of 200 feet on mitered towers.

425. Designs with general drawings and specifications were made by the writer in 1901 for a steel railroad viaduct (Fig. 289) for the Algoma Central Railway to cross the **Montreal river** and valley north of Lake Superior. The viaduct was 125 feet high and 1,500 feet long, and the design showed a series of trusses with curved bottom chords between towers battered both longitudinally and transversely. It was arranged for cantilever erection with a short boom traveler.*

426. The partial reconstruction of another American viaduct was made in 1903, when the deck of the **Portage viaduct** of 1875, which had been used for 28 years, was replaced by a heavier one on the old towers, which were originally proportioned for double track. The bridge (Fig. 285) has six 50-foot towers with two truss spans of 100 feet and one of 118 feet with trusses and girders 14 feet apart and ties on the top chords. In the original viaduct the trusses rested directly on the columns, which were about 20 feet apart at top, but in the reconstruction the new trusses were placed inside the old, and work continued without interfering with the regular traffic. New cross girders to support the longitudinal trusses

*Economic Length of Trestle Spans. H. G. Tyrrell, in Railroad Gazette, Dec.30, 1904.

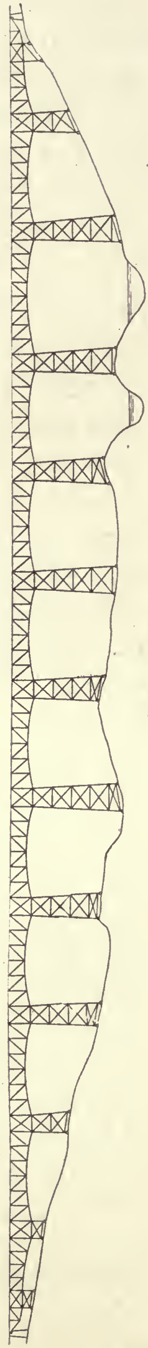


Fig. 289.

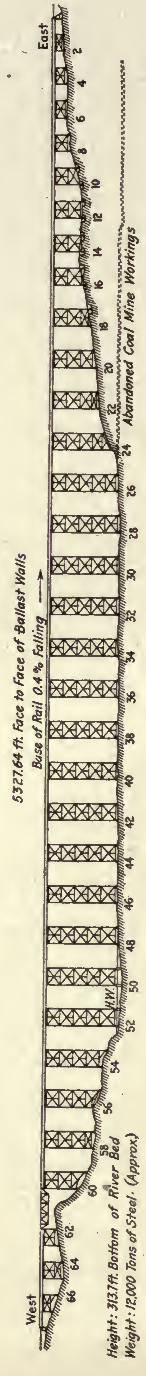


Fig. 292.

were inserted between the column tops. The reconstruction of the deck required 500 tons of new steel. A somewhat similar bridge over Caneadea gorge, 175 feet high, has 40-foot towers and 100-foot truss spans, which were erected with a derrick car. The Erie Railroad, which twice rebuilt its Portage viaduct, began in 1907 the construction of another over Moodna creek, 182 feet high and 3,200 feet long, on a 2 per cent grade, with alternate spans of 40 and 80 feet and girders 5½ and 9 feet deep respectively. Towers are 19½ feet wide at top for future double track, but only one pair of girders, 6½ feet apart, were placed at first. The Stony Brook Glen viaduct, 242 feet high with 40 and 80-foot spans, has all girders 7 feet apart, and a uniform depth of 8 feet, the girders being erected by a derrick with 100-foot boom. The

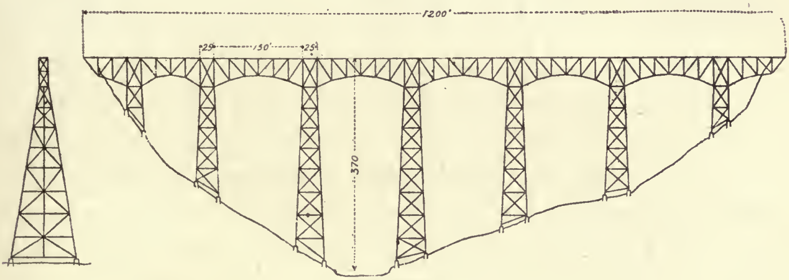


Fig. 290.

Richland Creek viaduct (1906), near Bloomfield, Indiana, 158 feet high with 40 and 75-foot spans, has girders with a uniform depth of 7 feet like the last one mentioned and the Boone viaduct, Iowa. The one at Bloomfield is 2,215 feet long for single track, contains 3,000 tons of steel, and was erected in 50 days by a force of forty men.

427. Designs were made in 1906 by H. G. Tyrrell for two viaducts to cross gorges in the Rocky Mountains (Fig. 290), one of which had a height of 420 feet, higher than any other in America, and exceeded only by the recently completed

Fades viaduct in France. In both designs towers with transverse and longitudinal batter supported truss spans for cantiliver erection. These designs were made in connection with an investigation of the economic and most suitable type of structure for the proposed crossings. In the following year several bridges of this type with shorter spans were erected on the Guatemala Railroad, those at El Rodeo and Las Vegas designed for cantilever erection with short-arm travelers, and intermediate 75-foot spans 12 feet deep and 10 feet apart. The towers have stiff diagonal bracing without horizontal struts, and 4-foot box girders at top, 18 feet long. In the same year complete designs with details, estimates and specifications were prepared by the writer for a street viaduct of very unusual

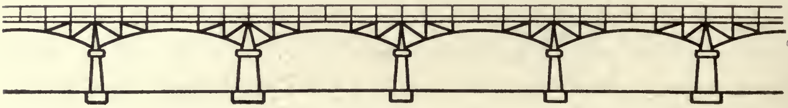


Fig. 291.

proportions over the railroad yards at Ogden, Utah (Fig. 291). The main viaduct was 2,260 feet long with thirty-one arch spans, and at one end was a double trestle approach 620 feet long leading up to the deck, with five more arches parallel to the tracks. The whole bridge, therefore, contained thirty-six arches of about 60 feet and a length of 2,880 feet. A somewhat similar one with one end approach at right angles to the main viaduct, was outlined by him, to cross the railroad yards at Pocatello, Idaho.

428. Two viaducts of 1908, which were erected by cableway, are those at Colfax, California; and Makatote, N. Z. The Colfax bridge over the Bear river is 190 feet high and 810 feet long, with a pair of central cantilevers over the river similar to the Pecos viaduct on the Southern Pacific. The

trusses of the cantilever, which have pin connections and rod bracing, are in the plane of the sloping columns rather than the vertical, and the remaining part, with 40 and 60-foot spans, have girders 7 feet apart with a uniform depth of 5 feet. The span of cableway was 830 feet. It was proportioned for only twenty-ton locomotives, but provision was made for increasing its capacity. Makatote gorge, New Zealand, 300 feet deep, is crossed by a single-track viaduct 840 feet long, with five towers 36 feet long supporting 100-foot truss spans, the whole being erected similar to the one at Colfax. Columns are 9 feet apart at top and are battered two inches per foot at each side. It contains 1,000 tons of steel and is the design of P. S. Hay.

429. Three large and unusual trestles were erected in Canada in 1908 and 1909. The **Cap Rouge** viaduct on the Transcontinental Railway is 173 feet high, with alternate spans of 40 and 60 feet, and three-deck truss spans. The two columns of each bent, 9 feet apart at top, are made of two rolled steel beams latticed together, and the longitudinal tower bracing is arranged with a minimum number of heavy members. The Battle River viaduct on the Grand Trunk Pacific Railway in Alberta, 184 feet high and more than half a mile long, has plate girder spans with uniform bent spacing of 50 feet in all bays, and a single, deck-truss span of 150 feet. But the largest one in Canada is the new **Leithbridge viaduct** (Fig. 292) on the Canadian Pacific Railway over the Belly river and valley in Alberta. It consists of alternate spans of 67 and 100 feet half through plate girder spans with girders 16 feet apart on centers and 8 feet deep. Half-through construction was adopted to prevent a train from leaving the track in case of derailment, a plan which was previously used on the Garabit viaduct in France, and later on trestles in New Brunswick. The great tower width of 67 feet made it eco-

nomical to use horizontal struts and diagonal tension members, rather than diagonal struts without horizontal members. Each 100-foot girder weighs 30 tons, and the 67-foot girders 15 tons each. They were erected with a steel traveler, the weight of which was 356 tons. Columns are 26 inches square, built up of plate and angles with cover plate, and the structure contains 17,000 cubic yards of concrete, 1,700 concrete piles, and 12,200 tons of steel. Manufacture was done by the Canadian Bridge Co., under the direction of J. E. Schwitzer, engineer for the railroad company. A trestle with a different style of tower (Fig. 293) was erected near Greenville, Maine, 1909.

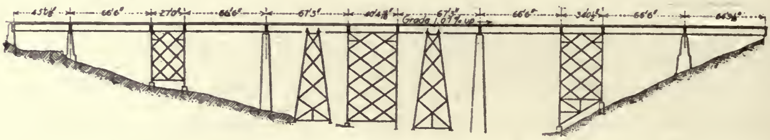


Fig. 293.

430. The **Fades viaduct,** 1,231 feet long, in three spans, has the longest continuous spans in the world, and is remarkable for its great height, and its large masonry piers. It crosses the valley of the Sioule river near Vauriat, France, with the rail 435 feet above the water, which is 8 feet higher than the Spoleto stone viaduct, which was formerly the highest of all. The center span of 472 feet has one 378-foot span at each side, terminating at one end with a masonry abutment and 78-foot arch, and at the other end with a girder span, which was substituted instead of an intended arch because of the yielding foundation. The two lines of lattice girder, 22 feet apart and 38 feet deep, are supported on two hollow masonry piers 303 feet high, which cost $130,000, or about twice as much as steel piers. The side spans were erected on false work and continued over the piers to meet in the center.

431. A table of the largest viaducts described, with their heights and lengths, in order of date, is as follows:

	Date.	Height feet.	Length feet.	Weight tons.
Crumlin, England	1857	210	1,800	......
Belah, England	1861	180	960	......
Fribourg, Switzerland ..	1863	250	1,300	......
La Bouble, France	1872	216	1,300	......
Verrugas, Peru	1872	256	575	......
Portage, New York......	1875	203	818	655
Kinzua	1882	301	2,053	1,400
Marent Gulch, Montana..	1884	200	800	843
Loa, Bolivia	1888	336	800	1,115
Malleco, Chili	1891	310	1,200	......
Pecos, California	1892	320	2,180	1,820
Boone, Iowa	1901	185	2,685	6,200
Gokteik, Burmah	1900	335	2,260	4,850
Makatote, New Zealand...	1909	300	860	1,000
Fades, France	1909	435	1,228	......
Leithbridge, Canada	1909	314	5,327	12,200

From the above it appears that the Fades viaduct is the highest, and the Leithbridge the longest and heaviest, while the Boone and Gokteik are the next largest. Their relative artistic merits and economic proportions are discussed elsewhere.

CHAPTER XVI.

SOLID CONCRETE BRIDGES.

432. Many of the largest masonry bridges of recent years have arch rings of solid concrete without reinforcing, or if metal was introduced it was for uniting the material into a solid monolith rather for resisting tensile stresses. Bridges of solid concrete are similar in principle to those of stone masonry, and in the transition from one kind of material to the other, plain concrete without reinforcing antedates the later combination of concrete and metal. A concrete foot bridge at Amalfi, Italy, on the Gulf of Salerno, said to have originated with the Moors about the sixth century, is still in fairly good condition. It is 5 feet wide, 10 feet above water, and 23 feet long, the arch ring being perforated with a series of transverse circular openings. Many old Roman bridges and aqueducts which were faced with stone had concrete backing and filling, but it was not till the middle of the nineteenth century that solid concrete was extensively used without stone facing. The **Grand Maitre Aqueduct** (1850-65), which conveys water from the river Vanne, 94 miles distant, through the Forest of Fontainebleau, and over the Loing river to the city of Paris, is borne on a long series of concrete arches without stone facing, and this work was the beginning of modern concrete bridge building. Ten years after the completion of the Paris Aqueduct, some concrete bridges were built in Switzerland, but it was not till 1890 that the new material came into general use. In the last decade of the nineteenth century concrete bridges appeared at Munderkingen, Verdun, Kirchheim, Inzighofen, Imnau, and Miltenburg, the last three

having hinges at the springs and crown. A small concrete bridge of 31-foot span was placed in Prospect Park, Brooklyn, in 1871, but the first important concrete bridge design in America was one proposed in 1885 by Thos. C. Clark for crossing the Harlem river at New York City, with three semi-circular arches of 285 feet. Mr. Clark outlined a bridge 150 feet high, 100 feet wide, and 1,200 feet long with stone facing, at an estimated cost of $3,500,000. But the present twin steel arch was accepted instead, and the first solid concrete arch bridge actually built in America was a small one, 34 feet wide, over Pennypack Creek at Philadelphia, with two spans of 25 feet, wire mesh being embedded in the concrete for extra security. Two years later a 40-foot span appeared over Richmond Creek at Belleville, Illinois, which was at that time the largest of its kind in the United States.* Soon after this several of the large railroad systems, including the Pennsylvania, the Lake Shore and Michigan Southern, and parts of the New York Central, began renewing their old steel bridges in masonry, at first using stone facing on the piers and spandrels. Among the important **railroad bridges** of the time are those over the Susquehanna at Rockville, over Big Muddy river at Grand Tower, Illinois, and others at Mechanicsville, Thebes, Ashtabula, Riverside, Long Key, and the Danville and Terre Haute bridges of the Big Four Railroad. Similar construction was adopted on the West Highland Railway in Scotland (1898), when many of their bridges, most of which had spans of 30 to 50 feet, were built in concrete. One, however, at Borrodale, had a span of 127 feet. In contrast to the many hinged concrete bridges in Europe, all heavy ones in America have fixed ends. The **Rockville bridge** over the Susquehanna, with 48 spans of 70 feet, cost upwards of $1,000,000 and is the largest of its kind.

*In 1881, three concrete railroad viaducts were erected on the Ewarton branch of the Jamaica Railway, one of them having four full centered arches of 50 feet, without reinforcement.

Piers and spandrels are faced with stone, but the centers and arch rings are concrete. The Big Muddy River bridge (1903), near Grand Tower, Illinois, for two tracks of the Illinois Central Railway, is a three-span concrete bridge replacing an old steel one, the piers of which were allowed to remain. The old piers were 9 feet thick and new ones, 22 feet thick, were built around them. The three main arches are solid concrete, elliptical, with semi-minor axes of 30 feet. The only reinforcing is in the spandrel arches supporting the floor and this was introduced for convenience of erection. The spandrel construction, with arch openings, cost more than solid filling, but was

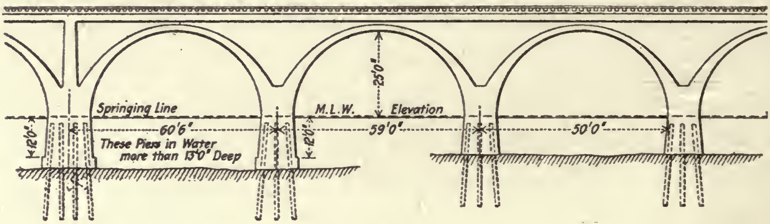


Fig. 294.

preferred because of its less load on the foundations. The Riverside bridge, carrying the San Pedro, Los Angeles and Salt Lake Railroad over **Santa Ana River,** was designed and erected under the direction of Henry Hawgood, chief engineer for the railroad company. The distance between pier centers is 100 feet, and as the piers are 14 feet thick, the central arches are 86 feet, and the two end ones 38 feet. It is all solid concrete without reinforcing, contains 12,500 cubic yards of concrete and cost $185,000. The Long Key Viaduct (Fig. 294) is one of several similar structures, carrying the Florida East Coast Railway from the main land to the port of Key West. The aggregate length of the viaducts is six miles, and this one, which is the longest, contains 180 semi-circular arches of 50 feet clear span, with a total length of 10,500 feet.

The regular piers are 9 feet thick, but every fifth one is an abutment pier 12 feet thick at the springs and all piers batter out 1 inch per foot at each side. The bridge is 15 feet wide at top for single track, and is made of solid concrete with metal reinforcement, the spandrels being filled with earth. The deck is 30 feet above mean water, the depth of which is 13 to 25 feet, underlaid with coral rock. The concrete railway viaduct over Finnan Valley, Scotland (1898) is 1250 feet long and 100 feet high, containing twenty-one semicircular arches of 50 feet each. All piers excepting two are 20 feet

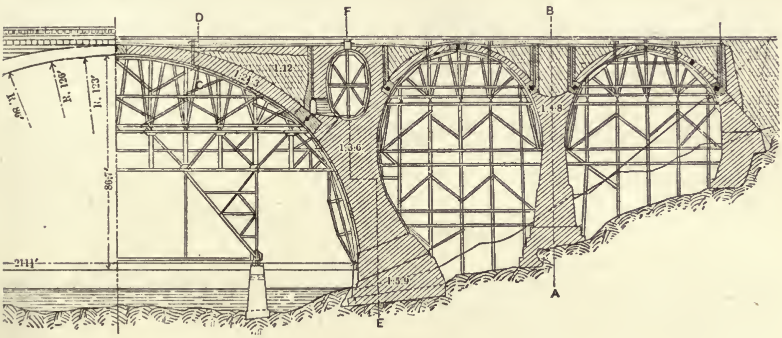


Fig. 295.

long and 6 feet thick at the top, the other two being 21 feet long and 15 feet thick, with hollow centers. The bridge is on a curve, and has three lines of longitudinal spandrel walls.

433. A great increase in span length was made in the Gruenwald bridge over the Isar river at Munich (1904), which has a 230-foot opening with three steel hinges, being the longest span up to that time. In the two following years other bridges were built at Ulm and Kempton, Germany, with spans of 210 feet, the latter having three hinges. The main arch of Gruenwald bridge was designed independent of reinforcing, though metal was afterwards added. The ring has a thickness of 30 inches at the crown, 36 at the springs and 48

at the quarter points. Spandrel columns supporting the floor system are two meters apart transversely, and four meters apart longitudinally. The Danville (Fig. 296) and Terre Haute (Fig. 297) arches of the Big Four Railroad are simi-

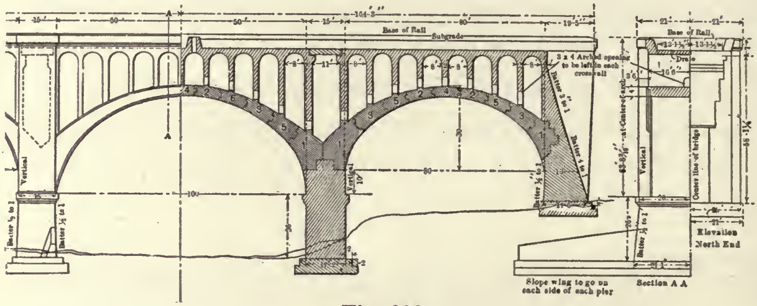


Fig. 296.

larly proportioned as solid masonry arches with reinforcing added, simply to unite the concrete.

434. The first American hinged concrete arch is in Brook-

Fig. 297.

side Park, Cleveland, over Big Creek. It has steel hinges and is without reinforcing, the intrados being a semi-ellipse 92 feet long and 9 feet rise. As the hinges were placed at the points of rupture the real arch span and rise were reduced

to 86 and 5¼ feet respectively. Hinges were similarly placed on the Kempton bridges in Bavaria, over the Iller river, where the span between hinges was reduced to 166 feet (Fig. 295). The two bridges at Kempton differ only in width, one having a deck 54 feet wide for four tracks, while the other is 25 feet wide for only two tracks, the wider bridge having two separate rings 4 inches apart.

435. Four large street bridges of the last decade in America, at Washington, Philadelphia, Cleveland and Spokane, are designed with twin arch rings similar to the Luxemburg stone arch in Germany (Fig. 32). The bridge at Washington, carrying Sixteenth Street over **Piney Creek**, has a parabolic arch

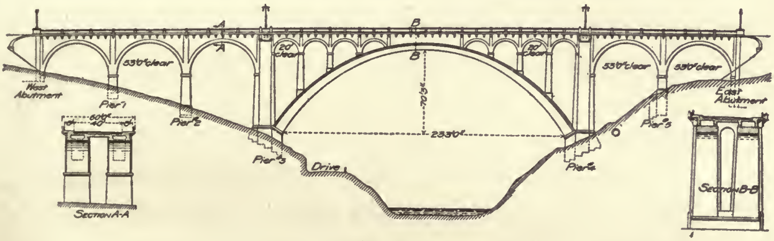


Fig. 298.

5 feet thick at the crown without reinforcement, only one of the twin arches being erected at first. The platform is supported on a series of spandrel columns, the construction being obscured by solid spandrel walls. The second arch ring was added in 1909, making the bridge 65 feet wide. Each of the two ribs are 25 feet wide, the space of 15 feet between them being bridged with 24-inch steel beams, 10 feet apart. The original work cost $50,000, and the addition $85,000 more. **Walnut Lane** bridge, Philadelphia (Fig. 298), connecting the residential suburbs of Roxboro and Germantown, crosses the Wissahickon valley at a height of 147 feet above the river, and when completed was the longest solid concrete bridge, having a clear span of 233 feet. It consists of two separate

arch rings 18 feet wide at the crown, increasing to 21½ feet at the springs, the two rings being separated at the crown by a space of 16 feet. The centering, which was a combination of wood and steel, was first used for one arch rib, and then moved over for the other rib. The main arch ring, which is an approximate ellipse, carries ten cross walls which support the floor system. At the ends are five semicircular arches of 53 feet. The bridge is solid concrete without reinforcing, excepting in minor details. The surface is rough, similar to pebble dash, but of coarser grain, exposing stone chips ⅜ inch diameter, formed by surface washing before the cement was hardened. The bridge is 585 feet long, 60 feet wide, and cost $259,000. George S. Webster, chief engineer. H. H. Quimby, bridge engineer. In addition to this bridge Philadelphia has more than fifty other concrete bridges, either solid or reinforced.

The longest masonry span in America is the new concrete arch bridge over **Rocky River** on Detroit Avenue, **Cleveland,** Ohio, with a central span of 280 feet and five end spans of 44 feet each. The main span, with two separate arch rings 18 feet wide, and 16 feet apart at the crown, support cross spandrel walls carrying the roadway. The brick pavement with two lines of interurban track for heavy cars, is 94 feet above low water. Beneath the floor are two subway chambers 3 by 11 feet for pipes and wires. The main arch rings contain no steel reinforcement, as calculations show that tension cannot occur in any part of the arch. Sidewalks project out about five feet over the face walls, and are supported on brackets. The central arch is similar to and 47 feet longer than the Walnut Lane bridge at Philadelphia, and the only longer masonry arches are those at Plauen, Germany, of hard slate, with a span of 296 feet, and the Auckland concrete arch of 320 feet. Plans are under way for replacing the

steel cantilever at Spokane with a four-span concrete arch bridge to carry Monroe Street at a height of 140 feet above Spokane river. The 281-foot segmental arch will have twin ribs 16 feet wide and 6 feet deep at the crown, with overhanging sidewalks, and cross spandrel walls 20 feet apart. At the ends will stand ornamental Dutch towers for public service and convenience. The ground on the north side of the river is naturally suited for an arch bridge, but on the south side the plan proposes an abutment carried down to 140 feet below street level, with four parallel walls each 4 feet thick, joined by numerous cross struts and braces.

436. The Lautrach three-hinged arch was quite economical, for its cost was only $21,600, while the estimated cost of a

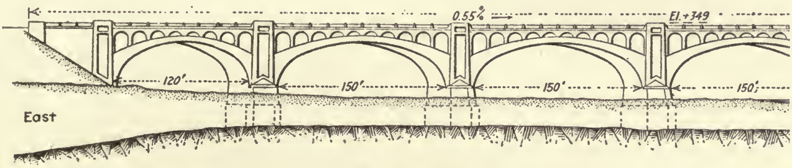


Fig. 299.

steel bridge for the same place was $26,200. Two solid concrete railroad bridges for double track, the design of Mr. Lincoln Bush, were completed in 1908 at Hainsburg, N. J., and Portland, Pa. (Fig. 299), with spandrel arches and U abutments, the last having seven spans and elliptical intrados and a skew of 65 degrees. Temporary three-hinge steel arches for centering were used on the Portland and Rocky River bridges, the cost in steel being less than in timber. The Wiesen bridge in Switzerland (1908) is made of concrete blocks cast in place, with a facing of rough natural stone, and is remarkable for its long span and great height of 325 feet. The four-track bridge over Grand river at Painsville, Ohio, replaced a four-span stone arch bridge which was considered too light, and like several other concrete railroad bridges, was

proportioned as a solid masonry arch, and reinforcing metal added afterwards, not, however, for resisting direct tensile stresses. A bridge over Gwynns river at Edmondson Avenue, Baltimore, has three spans with solid arch rings and a floor with asphalt pavement and double car tracks supported on spandrel columns. Other long spans are proposed at Larimer Avenue, Pittsburg, over Beechwood Boulevard, with a span of 300 feet, and one at Mannheim, Germany, over the Neckar river, with a span of 365 feet.

437. **Connecticut Avenue,** one of the chief thoroughfares of Washington, is carried over Rock Creek valley near its junction with the Potomac, about three miles from the Capitol building, on a concrete arch bridge 120 feet above the valley. It has five semicircular arches of 150 feet, and two of 82 feet, with a length between abutments of 1,068 feet, and a total length of 1,341 feet. The main arches are hingeless without reinforcing, but the spandrel arches contain metal bars. As the bridge is located in a fine residential district, its aesthetic appearance was a matter of considerable importance. The face rings of the arch, pier corners, mouldings and all trimmings below the granite coping are moulded concrete blocks. Other exposed concrete surfaces are bush hammered, presenting a uniform and pleasing appearance. The false work cost about $50,000, on which there was salvage of $15,000. Framing the falsework cost $9.00 per thousand feet of lumber, and molded cement blocks cost $15.00 per cubic yard. The whole bridge cost $850,000, equal to $639 per lineal foot, or $12.30 per square foot of floor surface. The design was a modification of one submitted by the late George S. Morison, and it was built under the direction of W. J. Douglas, bridge engineer, and E. P. Casey, architect.

438. The concrete arch at **Auckland, New Zealand** (Fig. 303), with a central span of 320 feet, is the longest on record,

and replaced a light suspension bridge. Larger ones have been projected, including one over the Mississippi river at Fort Snelling, Minn., with two spans of 350 feet, but none have materialized. In addition to the central span, the Auckland bridge has several concrete girder spans of 35 to 81 feet, the longer ones having open webs. The approach at one end is 305 feet long. The bridge is 40 feet wide, including two 6-foot sidewalks, 147 feet high above the valley and 910 feet long, and the two arch rings are hinged at the springs and center. The floor is paved with asphalt and the walks with cement. It was designed by R. F. Moore, engineer for the Ferro-Concrete Co. of Australasia, and built under the direction of W. E. Bush, city engineer of Auckland. Construction was commenced in February, 1908, and work completed in April, 1910, at a cost of $170,000. Two parallel arch rings supporting the spandrel columns are connected by wide reinforced concrete ties. The bridge adjoins a residential district, and beneath it at one end are the graves of New Zealand pioneers.

439. The construction of a great memorial bridge at the city of New York to commemorate the explorations and discoveries of Henry Hudson has been seriously considered for several years. The location selected is on an extension of Riverside Drive over Spuyten Duyvil Creek. Several alternate plans were prepared, but the one accepted by the Municipal Art Commission was a concrete arch. Metal was considered inappropriate for a great memorial structure, and all steel designs were therefore rejected. The accepted design shows a central 703-foot arch with seven semicircular end spans of 108 feet, and a clearance at the center of 183. The main arch would contain 8,500 tons of steel in its twelve arch ribs, not merely as concrete reinforcement, to resist bending stresses, but to assist in resisting compression, and thereby reduce the amount of masonry. There would be two decks,

the upper one with a 50-foot driveway and two 15-foot sidewalks, while the lower deck, 70 feet wide, would carry four lines of electric railway, but it is intended to omit the lower deck until needed. The main piers would be 180 feet wide, and the estimated cost of the whole structure is $3,800,000. The weight which the falsework would have to support during construction would be 100,000 tons, and this would cause a pressure on the entire ground area beneath the arch of two tons per square foot.

440. Solid concrete bridges with spans over 200 feet in length are given in the following table:

Name.	Span in feet.	Date.
Rome, Italy	328	1911
Auckland, New Zealand	320	1910
Spokane, Washington	281	1909
Cleveland, Ohio	280	1909
Philadelphia, Pennsylvania	233	1906
Gruenwald, Bavaria	230	1904
Kempton, Germany	211	1906
Ulm, Germany	210	1905

CHAPTER XVII.

REINFORCED CONCRETE BRIDGES.

441. The existence of bridges in a good state of preservation, which were built many centuries ago, some of them before the Christian era, is the basis of faith and confidence in concrete bridges. Among the early bridges are those on the aqueducts of Rome, Nimes, Carthage, Antioch and Segovia, dating from the first century, and the Bourgas (Fig. 45) and Spoleto aqueducts of the sixth and eighth centuries. Pont du Gard (Fig. 44), a bridge over the Garden river in the Nimes aqueduct, is perhaps the best preserved of all and has lasted for about 1,900 years. Many old road bridges of stone and concrete remaining from ancient times are further evidence of the superiority of concrete and masonry over all other kinds of building material. These road bridges include Ponte Rotto (142 B. C.) (Fig. 5), Pons Fabricius (62 B. C.), the bridge of St. Angelo at Rome, and one at Rimini, Italy (19 B. C.) (Fig. 9), as well as many of a later period throughout Europe and Asia, many of which are well preserved and still in use.

442. In the construction of masonry arches it has long been observed that the arches settle at the crown when the temporary centers are removed, and the extrados joints tend to open at the haunches, these points being known as the points of rupture. To prevent these joints from opening, rods and iron bands have often been used in the extrados of the arch rings extending from the piers and abutments up to or

beyond the points of rupture. Brunel, when experimenting with arches, built a semi-arch of brick 60 feet long with hoop iron bond, which supported itself by cantilever action.

443. The building of modern reinforced concrete bridges began in Germany in 1867, when **Jean Monier,** an inventive and ingenious gardener, made large cement flower pots and urns strengthened with a single layer of wire mesh. In the next few years he extended the construction to tanks, bins and arches, and protected his inventions by German patents. His arches had a single layer of wire mesh near the extrados only, with wire of the same size in both directions. These patents were introduced into the United States in 1884, and the same year rolled iron shapes were first used for reinforcement by R. Wunsch. Sir Shafto Adair built a concrete bridge in 1871 over the Waveney at Homersfield, England, with metal reinforcing frames, from designs by H. M. Eyton of Ipswich. The arch had a span of 50 feet, a rise of 5 feet 3 inches, and the skeleton iron frames were embedded in Portland cement concrete, over 100 tons of concrete being used.

444. The first reinforced concrete arch in the United States was in Golden Gate Park, San Francisco, in 1889. It was a single 20-foot span, 4¼-foot rise and 64 feet wide, with curved and ornamental wing walls, and imitation rough stone finish. Another one was placed in the same park two years later, and a somewhat similar ornamental bridge was built in Union Park, Chicago, in the year 1890. The latter crosses the park lagoon and is approached at either side by steps, the side wall of the steps being a continuation of the wall enclosing the pond. It is apparently more of a park ornament than for real use, though it serves both purposes. It has ornamental lamps and railing and in the summer season is further ornamented with large urns filled with growing plants and flowers.

445. Lack of definite knowledge in reference to the be-

havior of reinforced concrete arches under live loads was a serious obstacle to their development, and during the years 1890-95 the Austrian government conducted extensive experiments on full size concrete arches. The result of the experiments was satisfactory, and complete reports of the investigations were published in many of the engineering and scientific journals of America and Europe. Previous to this time, no exact or scientific methods of proportioning them were known, and progress was slow, but from the completion of the Austrian experiments in 1895 to the present time, the building of reinforced concrete bridges has greatly increased. Other valuable tests were made at Albany, N. Y., in 1910. Cast iron bridges with wrought iron ties were the prototype for reinforced concrete construction, for cast iron, which was strong in compression, but weak in tension, was supplemented with wrought iron tension bars. Professor Melan saw that wire mesh reinforcement with wires of the same size in both directions was faulty in principle, and he patented another and improved method of reinforcing arches by placing structural shapes lengthwise of the arch embedded in the concrete, using curved rolled beams two to three feet apart for small spans, and deeper lattice frames three to five feet apart for larger ones. His patents were introduced into the United States in 1893 by Von Emperger, and under these patents many of the best concrete bridges are built. There were at that time about 200 concrete bridges in Europe, most of them on the Monier patents, and during the next ten years, 1894-1904, about 100 concrete bridges were erected in the United States, in spans up to 125 feet. The reinforcing was at first used only in the arch ring, but in later years metal was inserted throughout the whole bridge or wherever there was possibility of tension in the concrete. Mr. Thacher was the first in America to use the elastic method for proportioning arches, and in 1894

he built a 30-foot highway bridge at Rock Rapids, Iowa, which was the first for heavy road travel in America. When it became evident that ordinary iron and steel bridges seldom lasted longer than twenty to forty years, the more general adoption of concrete was rapid. Several American railroads, after repeatedly renewing their metal bridges for increased loads and rolling stock, substituted concrete and masonry for later renewals, knowing that when properly built they would last for centuries.

Fig. 300.

446. Concrete arches with steel reinforcing to resist tensile stresses in the arch ring from bending are confined almost entirely to highway and foot bridges, heavier and solid arch rings being used for train and engine loads. The heavier bridges with greater mass better absorb the shock from rapidly moving locomotives. Reinforced concrete bridges are extensively used in **parks and private estates** where architectural treatment is desired, and they may be found in the parks of

San Francisco, Chicago, New York, Boston and other large cities. The Eden Park and Stockbridge bridges by Emperger, both completed in 1895, demonstrate some possibilities in concrete. The one at **Eden Park,** Cincinnati (Fig. 300), is a handsome 70-foot Melan arch 33 feet wide, crossing Park Avenue, one of the main park drives. It has an 18-foot roadway and two 5-foot walks with an arch rise of 10 feet and ring thickness of 15 inches at the crown, and 48 inches at the springs. The reinforcement consists of 9-inch curved beams 3 feet apart. The whole bridge is ornamental, for the soffit is paneled and the balustrade heavy and artistic, while the spandrels and abutments have heavy panels and moldings. Tenders received for a stone bridge were as high at $12,000, while the contract price for the concrete bridge was only $7,130, which probably did not include all items of expense, for the original plan had urns and other ornamentation above the railing. One of the lightest concrete bridges ever built is the footbridge at Stockbridge, Mass., over the Housatonic river, connecting Laurel Hill with Ice Glen. It has a clear span of 100 feet, a total length of 124 feet, a rise of 10 feet, and a clear roadway of 7 feet. The crown thickness is only 9 inches, increasing to 30 inches at the springs, and it is reinforced with 7-inch curved steel beams 28 inches apart. It stands on rock foundation and contains only 22 cubic yards of concrete. After completion in 1894, at a cost of $1,475, it was tested with a load of 25 tons.

447. The introduction of this new construction marks one of the most important forward movements in bridge architecture, since the Romans discarded wood and built the Tiber bridges of stone, and there is little doubt that concrete bridges will gradually replace metal ones for ordinary spans. When preparing for the California Midwinter Exposition of 1896, the **City of San Francisco** placed several ornamental bridges at

the Fair Grounds in Golden Gate Park, among which are two rustic bridges with two spans in each, a Roman bridge at Stow Lake, Alvord Lakelet bridge at Haight Street entrance, and two on the main drive near the museum. The rustic street bridge with twin spans fits well into the landscape, though a single span or three shorter ones would have looked better. The exposed arch rings are of stone, but the soffits are of other material, the rustic features occurring only on the spandrel faces, wing walls and parapets. It was started in 1893 and carries a drive over the lake. Another two-span rustic bridge carries a double line of electric railway over the drive at Ocean Beach, appearing like a natural bridge, and the semi-tropical plants growing on and about it are characteristic of the region. The Roman bridge carries a park drive over Stow Lake, the characteristic feature of the bridge being its plain surface with flat arch and curved parapet. It is solid and heavy in contrast to many of the very light ones often used for carriage and pedestrian travel. The Alvord Lakelet bridge carries the driveway over the main foot walk at the Haight Street Park entrance. It is almost buried in the foliage and the soffit is thickly hung with artificial stalactites. A bridge on the main drive crossing a foot walk near the museum is very beautiful, and displays a high degree of decorative work on the spandrels and along the roadway where lines of stone and concrete railing separate the foot walk from the carriageway. When examined and photographed by the author after the earthquake of 1906, the barrel of the arch was damaged and broken, but the upper part and railings were uninjured, though the museum building close by was seriously shaken and broken. Another bridge near the museum, surrounded by semi-tropical vegetation, has wide drafts on the stone courses, curved wing walls and other ornamental features. Other park bridges of 1896-97 are those at Champlain,

Ill., St. Louis and Hyde Park. The Champlain bridge, on the state college grounds, is the work of Professor A. N. Talbot. Franklin bridge, in Forest Park, St. Louis, is a single-span Melan arch, the thickness of ring varying from 11 inches at the crown to 30 at the springs, with ornamental lamp posts at the four corners. The Hyde Park bridge on the Vanderbilt estate, crossing Crum Elbow Creek, is very artistic, with elliptical arch and curved wing walls and a railing of beautiful design. (Fig. 314.)

448. Three of the largest early concrete bridges are those at Maryborough, Australia (1896), Paterson, N. J., and Topeka, Kan. (1897), the last two being the work of Mr. Thacher.

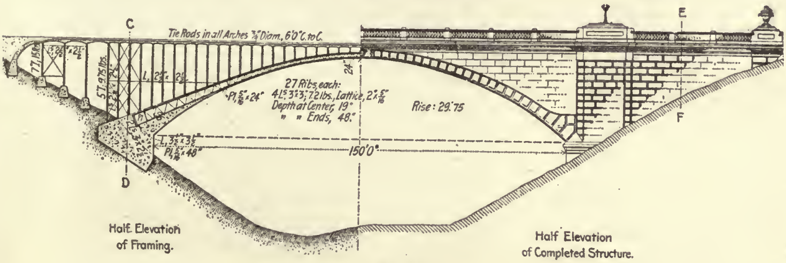


Fig. 301.

In the previous year Mr. Thacher submitted designs for two bridges in Schenley Park, Pittsburg, with openings of 150 (Fig. 301) and 300 feet, and reported that spans up to 500 feet were economical and practicable. These designs showed reinforced side arches with floors supported on a system of steel beams and columns in open chambers, extending out into the abutments, the face of spandrels and abutments being enclosed with thin curtain walls. The Maryborough bridge, with eleven spans, was the largest at the time, but its length was exceeded in 1897 by the Topeka bridge (Figs. 302, 308), over the Kansas river, which contained a central arch of 125 feet, though this span was soon after exceeded by others. A vertical curve on the roadway of the Topeka bridge would

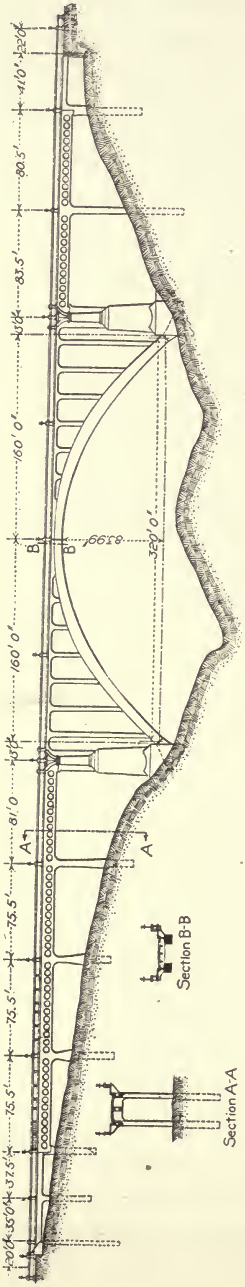


Fig. 303.

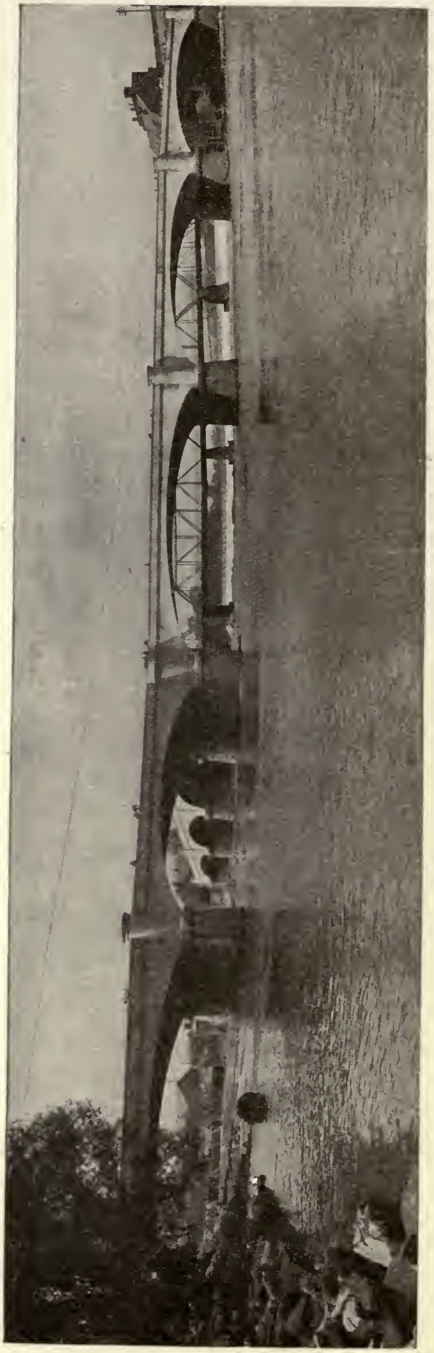


Fig. 305.

have looked much better than the break of grade at the center, which is very evident. The Maryborough bridge was designed to be submerged 20 feet during floods, and it is therefore much shorter than if placed at a higher level. It contains eleven arches of 50 feet and is 613 feet long with a clear road of 21 feet. On account of being occasionally

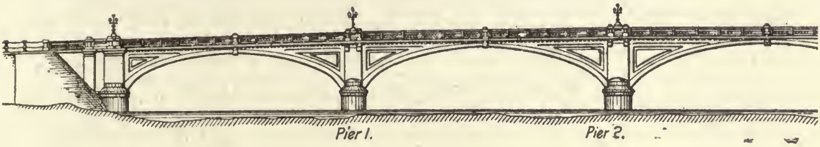
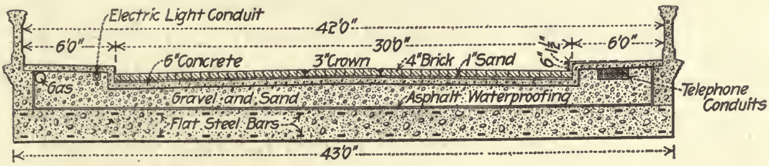


Fig. 302.

submerged, the balustrade is solid and the lamp posts are removable.

449. Reinforced concrete has been used to cover and preserve the structural steel of overhead bridges, as on the foot bridge at Cedar Rapids, Iowa, which is 341 feet long and 6 feet wide, with stairs at each end. The steel girders were first enclosed with ⅞-inch boards on which wire mesh



Section at Crown of Arch,
Fig. 304.

or expanded metal was fastened with a ⅜-inch space between the boards and metal. The surface was then covered with 1 inch of cement plaster. The whole bridge cost $7,500. The VanBuren Street Bridge, over the Illinois Central tracks, at Chicago, was similarly protected in 1897 with tile.

450. A Y bridge with three arms, over the Muskingum and Licking rivers, **at Zanesville, Ohio** (Figs. 304, 305), is

the fourth one on the same site, former ones having been either wrecked or removed. In spanning the two rivers at their junction, the bridge was built with three arms meeting at a center pier. The east arm is 400 feet long with three spans of 122 feet, the west arm 250 feet long with two spans of 122 and 90 feet, and the north arm 250 feet long with three spans of 81 feet. The foundations rest on rock, and a flat arch rise was used because of the small distance between the desired grade and high-water level. A somewhat similar metal arch bridge over the Danube at Budapest was erected in 1875, and the Genoa bridge, with arches in two arms, has a suspension in the third arm. The X bridge over the Sarthe at Mans,

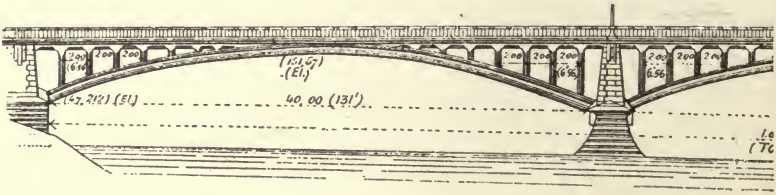


Fig. 306.

France, just below the Ysoir bridge, carries an electric railroad on one branch and a steam railroad on the other. The platform, which has an outside width of about 13 feet, consists of a concrete slab reinforced with old rails supported on a pair of steel plate girders about 5 feet apart, the whole standing on a series of small single piers. The combined length of the two parts is 360 feet, and the total cost was less than $1.25 per square foot of deck.

451. **Hinged masonry arches** have been more favored by European than by American engineers. One of the first of this kind, crossing the Laibach river, is faced with ornamental molded concrete slabs, and the concrete balustrade is relieved by bronze candelabra and portal figures. Other hinged arches

in Europe were erected at Chatellerault, France, 1899, and at Soissons, 1903. The piers of the Chatellerault bridge (Fig. 306) stand on concrete steel grillage and each pier has four vertical metal supports fastened to the foundation. The exterior 5 inches of the piers is fine concrete with ordinary concrete center. It was completed in the remarkably short space of three months. A reinforced concrete bridge over the Tagliamento river near Pinzano, Italy, is in two stories somewhat like Pont du Gard, with the deck 86 feet above the water. Its total length with approach is 600 feet, and in the lower story are three twin arch rings of 160 feet, between piers 13 feet 3 inches thick, while the upper story consists of a series of 35-foot arches supporting the 17-foot roadway.

452. In the year 1900 the United States government asked for competitive designs for a memorial bridge to cross the Potomac river at Washington, and several of the designs submitted were of reinforced concrete. One, by Mr. Burr, had a width of 60 feet, a length between abutments of 3,400 feet, and one deck, without provision for car tracks. There were six segmental reinforced concrete arch spans of 192 feet and 29-foot rise with 53-foot clearance underneath. A double leaf bascule draw span centrally located between the arch spans had an opening of 159 feet and a distance between trunnions of 170 feet. The Washington approach consisted of twelve semicircular reinforced concrete arch spans of 60 feet and 550 feet of embankment, while the Arlington approach had fifteen similar spans and 1,350 feet of embankment. The face rings of the main spans were 5½ feet deep at the crown and 9½ feet at the springs, with granite on the whole exterior face. In each main span were five concrete steel arch ribs 30 inches deep at the crown and 7 feet 3 inches at the springs, supporting a system of interior steel columns carrying the floor beams. Spandrel curtain walls with expansion joints rest upon

the arch rings and were shown faced with granite. Concrete floor arches between steel beams supported an asphalt road and granolithic walks. The estimated cost was $3,680,000.

A number of large **American cities** began about 1900 to adopt concrete deck arches for their new bridges, and among them were the cities of Indianapolis, Ind.; Washington, D. C.; Dayton, Ohio; South Bend, Ind.; Philadelphia, and Spokane. The first two bridges over Fall Creek, at Indianapolis, differing only in their width, were erected in 1899 and 1900. The Illinois Street bridge is 60 feet wide, while the Meridian Street bridge is 10 feet wider. Each has three spans of 74 feet between 8-foot piers, and the exposed surface of spandrel and

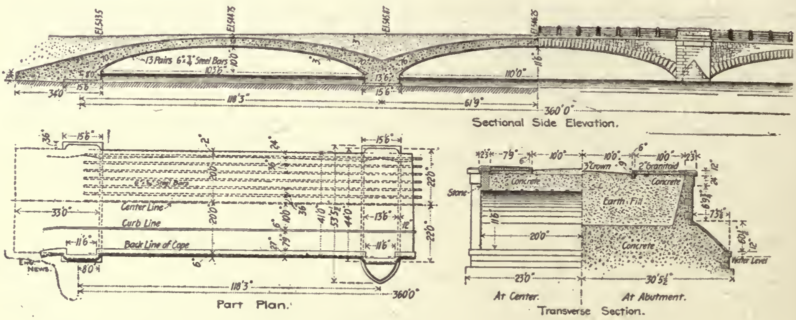


Fig. 307.

piers is faced with limestone. The railings are stone, but all other parts, including the arch soffits, are gravel concrete. The roadway of the Meridian Street bridge is paved with asphalt, but the other bridge has creosoted yellow pine blocks, and both of them have cement sidewalks. Other Indianapolis bridges are at Northwestern Avenue, Morris Street, Cruft Street and East Washington Street. The Northwestern Avenue bridge is similar to that at Illinois Street, with three spans of 74 feet. Above the piers circular pilasters are carried up to support retreats in the balustrade, which is very ornamental.

The Morris Street bridge, over White river, has five concrete steel Melan arches 90 to 110 feet long, with stone facing on parts exposed to view. Crossing from Green Island to the American side of the Niagara river, over the main channel, is a three-span concrete arch bridge faced with stone (Fig. 307). It was designed by the engineers of the Indianapolis bridges. It crosses the rapids where the water has a velocity of 24 miles per hour, and just below the bridge is the American Falls of Niagara. The body of the masonry is concrete reinforced on the Melan system, and for arches of so flat a rise the design is very artistic. The stone arch rings and facing with belt course of different material, and a smoother coping, together with the rounded pilasters at the piers, all unite to produce a pleasing effect.

The **Interlachen bridge,** Minneapolis, erected (1900) for the Board of Park Commissioners, spans two lines of electric car tracks and carries a roadway, with a foot path on one side and a bicycle track on the other. The face of the arch ring, the skew back and copings, are Kettle river sandstone, but all other facing is blue limestone, while the body of the arch is concrete steel construction on the Melan system. The city of **South Bend** has reinforced concrete bridges at Colfax and Jefferson Avenues, the first being a single span, while the Jefferson Avenue bridge (Fig. 310), over the St. Joseph river, has four elliptical arches of 110 feet each. Few concrete bridges in America show more artistic treatment. The pier ends have elaborate detail and are carried up to support retreats in the sidewalk. A moulded cornice relieved with dentils is mounted with a heavy ornamental railing. At the ends are steps leading down from the bridge to the water. Concrete has been used in this bridge true to its own nature and not worked to imitate stone, a plan that is commendable when well executed. **Sixth Street** bridge at Des Moines

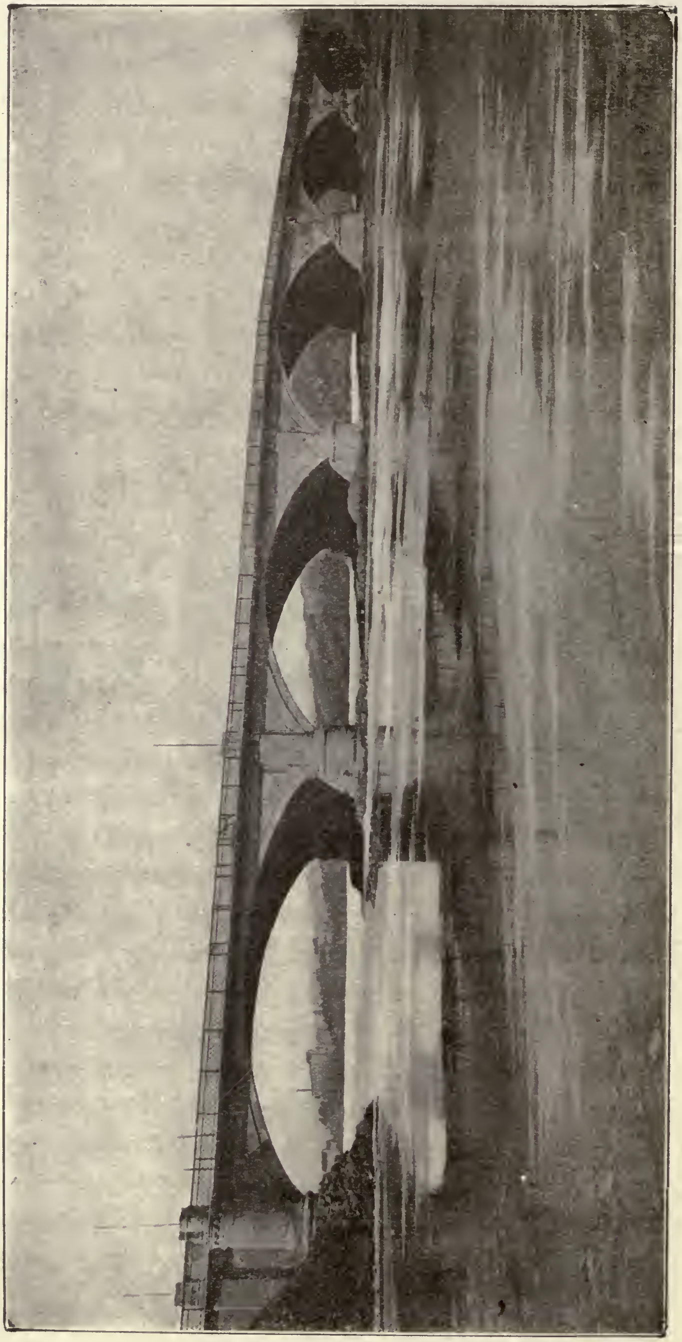


Fig. 308.

(1901) is one of the finest in America, for the elliptical arches are well proportioned, and the combination of vitrified brick face with concrete trimmings makes it unique. A bridge at Gary, Ind., shows some possibilities in concrete for single spans. The face of arch and spandrels are panelled and the wings are curved to facilitate approach. At either end of the arch are pilasters extending up to the cornice and forming in the balustrade pedestals for future lamp standards.

453. The Boulder faced bridge over **Rock Creek,** in the National Park, **Washington** (1901), is a segmental concrete arch of rustic design made to conform with the surroundings. The body of the arch is concrete reinforced on the Melan system with steel, and the soffit is darkened with lamp black to harmonize with the facing. The boulders of the arch ring extend down several inches below the soffit and partly obscure it. The bridge is located in a very beautiful part of the valley and is much admired. The concrete arch on Ross Drive over Rock Creek (1907), with a span of 100 feet, was built when the monumental solid concrete bridge at Connecticut Avenue was nearing completion. Other boulder faced bridges are at Hyde Park on the Vanderbilt estate, Atlantic Highlands, and one with rustic parapet in Marion County, Indiana. The last bridge is on an ordinary country road and is a type quite suitable for wooded parks or rural districts.

454. Two bridges over the Passaic river at Paterson and Clifton, N. J (1902), contain some unusual features, being proportioned to resist water pressure when submerged. The eleven reinforcing ribs are continuous over the piers and are securely anchored into the abutments, resulting in combined arch and cantilever action. Each rib consists of four old track rails, two in each chord, riveted together with plates between them, and the chords are united with web members. The

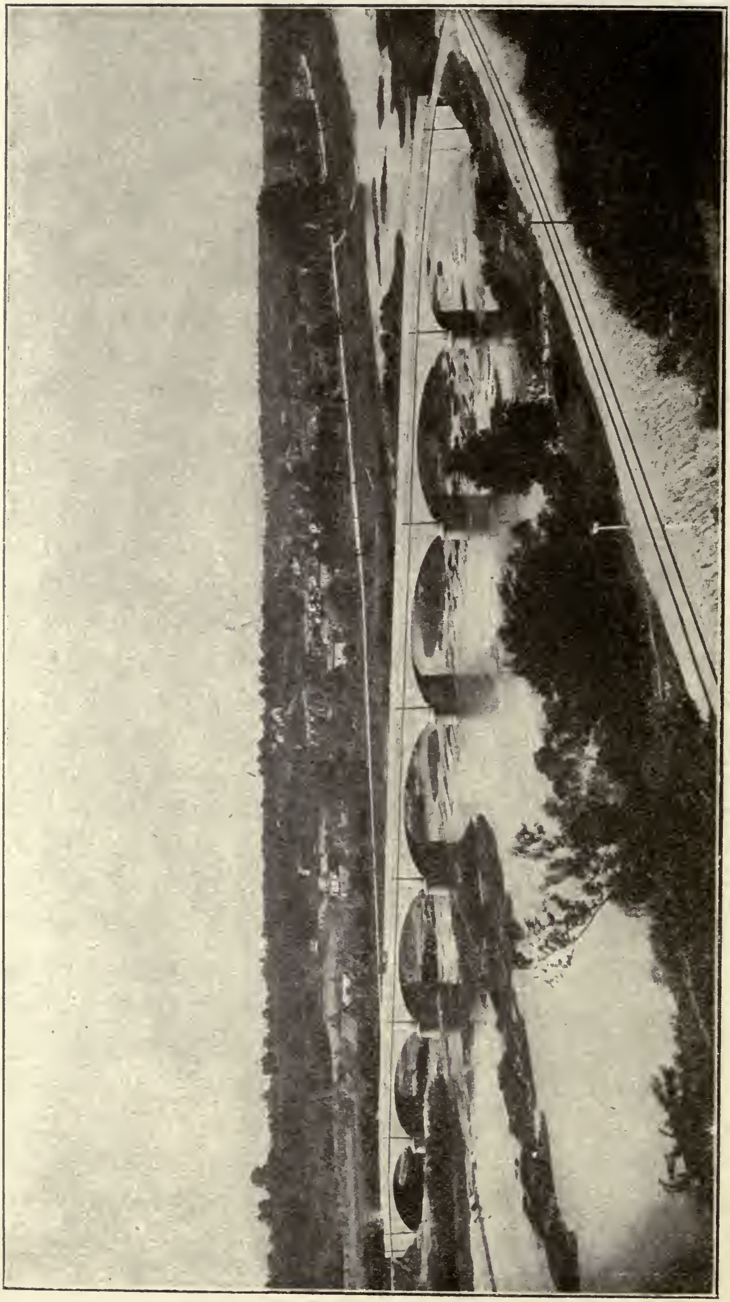


Fig. 309.

Arch Street bridge at Paterson has three spans of 58 feet with a 2½-foot rise and 50-foot road 170 feet long between abutment faces. The rings are cinder concrete, 20 inches thick at crown and 50 inches at the springs. It cost $38,000, but was seriously damaged in 1902. The Passaic river bridge at Clifton, N. J. (1902), with five spans of 60 feet, is similar to the last. Reinforcing ribs on both bridges are spliced at the points of contra flexure, and piers and abutments are faced with stone. The last bridge was submerged about two feet in the freshets of 1903.

455. Four large bridges with seven spans in each bridge were erected 1902-1905 at Waterloo, Iowa; Plainwell, Mich.; Peru, Ind., and Kankakee, Ill., the cost per square foot of floor surface being nearly the same in all cases, about $2.00 per square foot. The Kankakee bridge is a subsequent work of the engineers of the Topeka bridge, and the floor is made on a vertical curve. The **Wayne Street bridge** at Peru, Ind., (Fig. 309), was built in six months, June to December, 1905. The center one of the seven spans is 100 feet, and others 95, 85 and 75 feet, respectively, towards the ends. The clearance above low water is 24 feet, and the thickness of arch ring varies from 21 to 25 inches at the crown. Piers 6 feet thick at springs stand on bed rock. The arch rise varies in different spans from 13 to 15 feet, and the bridge contains 5,200 cubic yards of concrete and 50 tons of steel reinforcement. In January, 1907, it was severely tested when the water in the Wabash river rose to within five feet of the soffits, and the approaches at both ends were submerged 2 feet, but the bridge sustained no injury. Two other large bridges of 1904 and 1906, with five spans in each, are at **Grand Rapids, Mich.**, and New Goshen, Ohio, the lengths being almost identical. The Grand Rapids bridge is a typical example of the best American practice in slab arches. The center span is 87 feet, the two

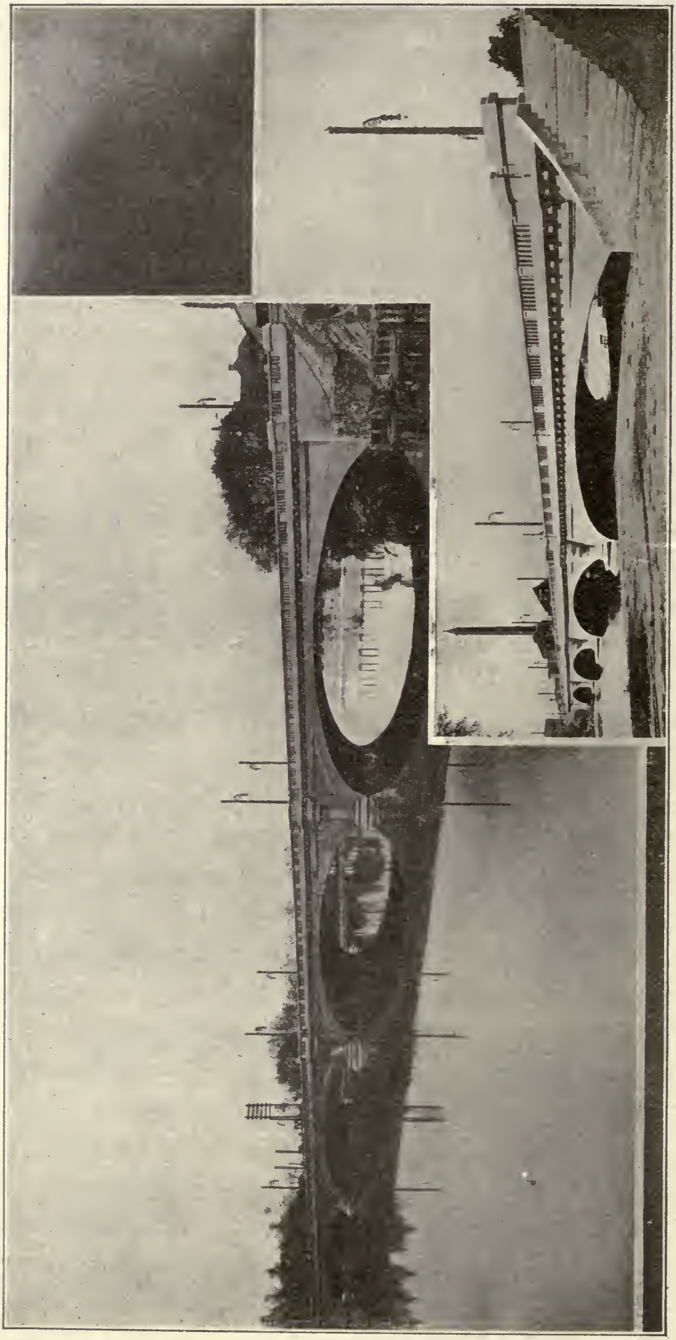


Fig. 310.

adjoining ones 83 feet, and the two end spans 79 feet each. It was designed by Wm. F. Tubesing, for L. W. Anderson, city engineer.

456. The City of **Dayton, Ohio,** erected three fine concrete bridges over the Great Miami river in 1902-6 at Main, Third and Washington streets, with seven spans in each bridge. Owing to a bend in the river above Main street the water in flood season rises 20 feet above low water level, and the banks are therefore confined by levees above and below the bridge. High water line is now a foot above the arch springs at Main street, with the street graded 2½% on one side of the bridge and 3½% on the other side. To increase the arch rise would have resulted in a steeper street grade, which was not desirable. Piers were made thin to avoid obstructing the already crowded channel. The center span is 86 feet, the two adjoining ones 83 feet, the next two 76 feet, and the end ones 69 feet. The bridge (Fig. 311) contains 150 tons of steel in the nineteen lines of reinforcing ribs, and 11,400 cubic yards of concrete. The distance from the upper surface of the brick pavement to the arch crown is only 13 inches, and the track rails are therefore very close to the masonry. The rise of the arches is such that the horizontal thrust on the piers is the same on both sides. The second concrete bridge over the Miami river at Dayton was at Third street, and the third one was at Washington street (Fig. 312). The last replaced an old iron bowstring bridge that was too light for the heavy car travel. All the Dayton concrete bridges are on the Melan system from plans by The Concrete Steel Engineering Company of New York. Wm. Menser, engineer.

457. Long concrete **street viaducts** over railroad yards have been erected at Jacksonville, Fla. (1903); Atlanta, Ga.; Knoxville, Tenn., and Winnipeg, Manitoba. The Jacksonville viaduct has sidewalk brackets projecting 3 feet 9 inches

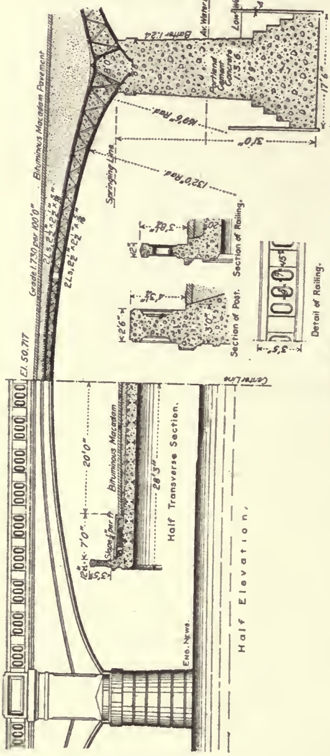


Fig. 311.

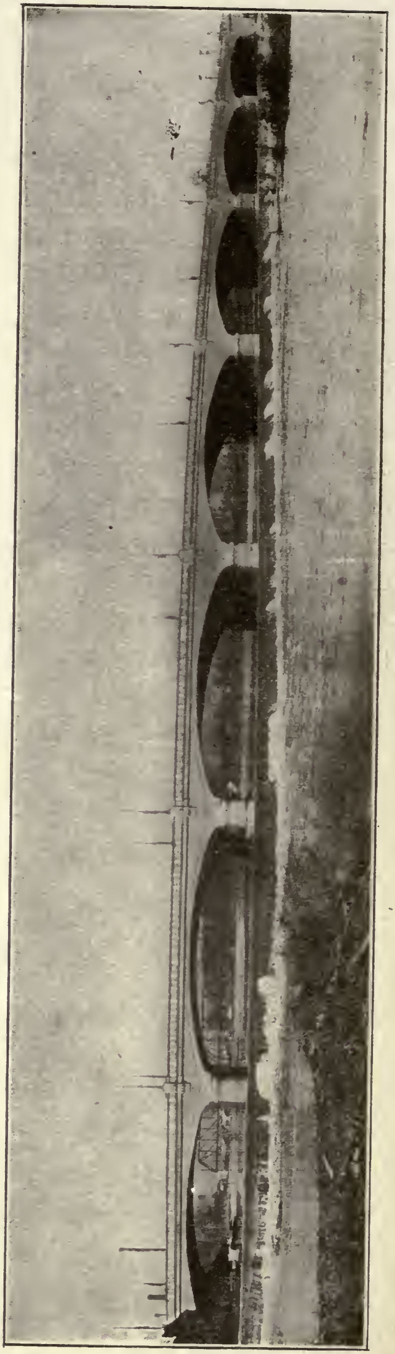


Fig. 312.

from the spandrels, and the arch rings are reinforced with twenty lines of Thacher bars 15 inches apart, and eight Melan frames 30 inches apart under the spandrels and car tracks. The Nelson Street viaduct at Atlanta, Ga., has ten spans of 20 to 75 feet, and a total length of 480 feet. The Knoxville viaduct is 767 feet long in thirteen spans, with overhanging sidewalks. Designs for a proposed concrete viaduct about 3,000 feet long, were made in 1907 by the writer to cross the railroad yards at Ogden, Utah, but steel and wood construction were found to be less expensive.

458. Many concrete **park bridges** began to appear in American cities soon after 1900, most of them being notable

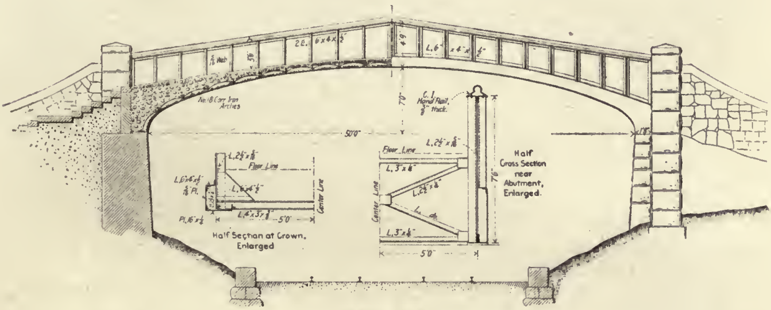


Fig. 313.

more for their artistic design than for their large proportions.* It frequently happens that a combination of steel and masonry in the same structure is offensive to the artistic taste, but in the park bridge at Madison, N. J. (Fig. 313), a pleasing effect has been produced. The bridge spans two lines of railway and has an opening of 50 feet, and the floor is 10 feet wide with stone and concrete steps at each end. The central arch girder is steel with a projecting fascia at the lower flange, representing a thin arch surmounted with a plate iron railing. The projecting fascia on the lower external face of the girders is 9

*American Park Bridges. H. G. Tyrrell, in American Architect, 1901.

inches wide at the crown, increasing to 24 inches at the springs. Each of the girders is capped with an ornamental cast iron coping, and the piers are surmounted with electric lamps. The whole bridge is surrounded with shrubs and flowers and altogether presents an artistic appearance. H. G. Tyrrell, engineer. (The Engineer, London, and Engineering News, 1900.)

A foot bridge at Columbia Park, Lafayette, Ind., has a 40-foot span and an under clearance of 8 feet. The crown thickness is only 9 inches, and beneath the water are tension rods embedded in concrete resisting the arch thrust. The Como Park foot bridge at St. Paul, Minn., built in 1903, for the Twin City Rapid Transit Company, carries traffic entering Como Park over the tracks of the street railway company. As large numbers of passengers leave the cars at the bridge, it was desirable that the structure should have a neat appearance. In order to avoid form marks on the exposed surface, the boards were covered with metal lath and neatly plastered with a fine coat before placing the concrete. The length between centers of abutment piers is 83 feet and the total width of arch is 17 feet, while the openings over spandrels and abutments are 12 feet long, and skew back piers 2 feet thick. The arch is reinforced with five Melan ribs in the concrete.

459. The overhead railroad bridge at the entrance to Forest Park, St. Louis, shows the architectural treatment of a horizontal girder. The relative grade levels of street and railroad prevented the use of an arch and an ornamental through plate girder bridge was used instead. The exposed fascia over the roadway is a concrete parapet concealing the steel girder behind it. The clear opening for the street is 70 feet, and the whole bridge in 1904 cost $25,000. This is the principal entrance to Forest Park and it adjoins a fine residential section of St. Louis. Other park features in the im-

mediate vicinity display the highest art of the landscape gardener and architect, and any structure lacking in artistic treatment would mar the surroundings. The curving wing walls

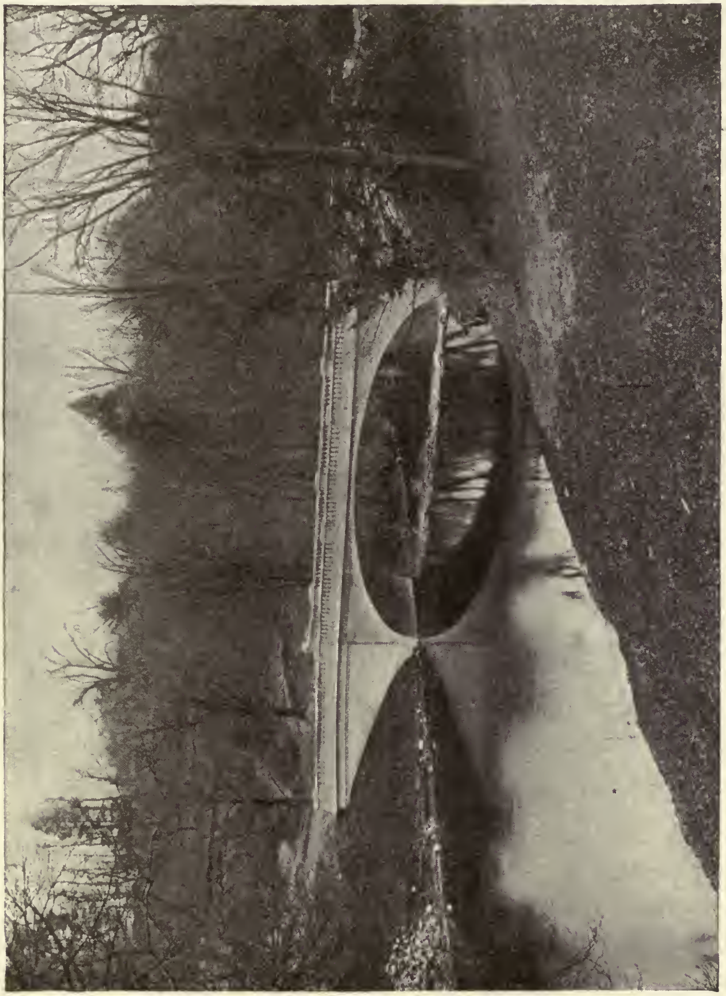


Fig. 314.

terminating in circular columns, add greatly to the general effect. The Yellowstone Park concrete arch (Fig. 315) crosses

the Yellowstone river just above the Upper Falls, over the rapids. Bridges adjoining water falls are usually placed below the falls, that passengers over the bridge may enjoy the view, but at Yellowstone the upper location was selected to avoid any obstruction of the view by the bridge itself. The roadway has a camber of 2½ feet and at the center is 43 feet

Fig. 315.

above the water. A bridge in Branch Brook Park, at Newark, N. J., carries Park Avenue over a waterway, walk and drive. It contains 6,200 cubic yards of concrete and 124 tons of steel, costing, without pavements, $84,000. Construction occupied five months, from August, 1904, to January, 1905, work being under the direction of the Park Commissioners of Essex County, New Jersey. A. M. Reynolds, engineer. Several fine park

bridges are located in and about New York, one at Newell Avenue in the Botanical Gardens being faced with granite. The outlines of the bridge with the different kinds of surface finish and its setting in the foliage produce a satisfactory effect.

At the little town of **Venice, in Lower California,** laid out with canals in imitation of Venice, Italy, are a number of interesting concrete bridges of curious design. The town is a watering place for travelers wishing to escape the severe cli-

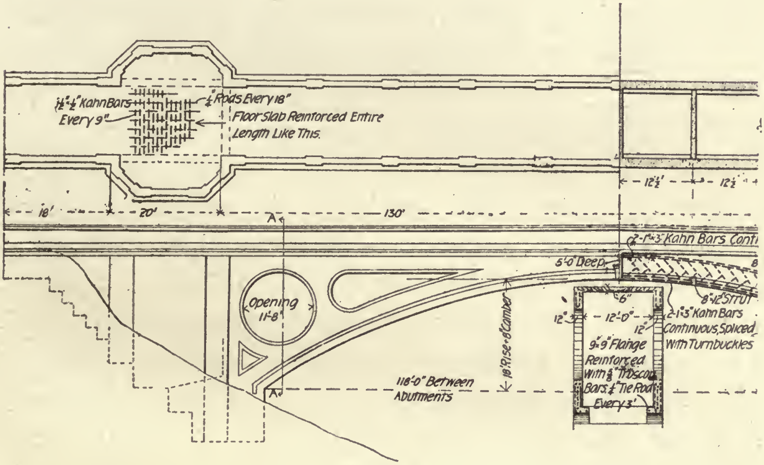


Fig. 316.

mate of northern latitudes. There are streets of tents and thatched cottages, with many features for the amusement and entertainment of visitors. In a district where novelties abound and where entertainment is a principal object, there is perhaps reason for the unusual decorations, which were doubtless suggested by the proximity to the sea coast. The arch faces are decorated with festoons of flowers and on the balustrades are huge and horrible images of sea monsters. An ornamental foot bridge in **Lake Park, Milwaukee,** near the pavilion, crosses a gorge 50 feet deep, and is much seen especially in the sum-

mer time (Fig. 316). The structural features consist of two reinforced concrete ribs 12 inches wide and 54 inches deep, with an inner flange on the lower side of the arch ribs. These ribs are 12 feet apart in the clear, and they support spandrel walls which carry the 6-inch reinforced concrete floor slab. Cross walls and struts 12 feet apart longitudinally connect the arch ribs, and between them is a double system of steel angle bracing, the ends of the angles being securely fastened in the concrete. Spandrel walls are 12 inches thick with expansion joints at each end adjoining the abutments. The arch ribs and abutments are a monolith and the floor is cambered 8 inches longitudinally for drainage. The abutment side walls are connected with cross walls which support a floor slab similar to that on the bridge. R. E. Newton, engineer.

460. **Ribbed arches** were not used to any great extent in America previous to the erection of the one in Lake Park, just described, but in the next few years others appeared at La Salle, Playa del Rey, Sandy Hill, Belvidere, Spokane, Washington, Denver, Jamestown, Wakeman and St. Paul. The bridge over a lagoon at Playa del Rey, a suburb of Los Angeles, is exceedingly light for so long a span. The **Sandy Hill** bridge (Fig. 317), over the Hudson, one of Mr. Burr's designs, has a long series of spans between piers 6 feet thick, the distance between abutments being 984 feet, and the extreme length 1,025 feet. The clear width between railings for carriages, electric railway and sidewalks is 32 feet. Beneath the bridge the river is rapid and shallow, and a few hundred feet below the site is a natural falls 60 feet high. A century ago an old toll bridge crossed the river just below the new site, but it was destroyed in 1832 and a new bridge was immediately begun, but never completed. The spandrels, pier faces, copings and railings are molded concrete blocks bonded into the masonry. The arch ribs are 32x14 inches at the crown, in-

creasing to 32x27 inches at the springs, supporting 12-inch spandrel walls which carry the 8-inch floor slabs and asphalt pavement. A temporary wood bridge was used during construction.

The method of building the ribs for the new Elgin-Belvidere Electric Railway bridge was somewhat similar to

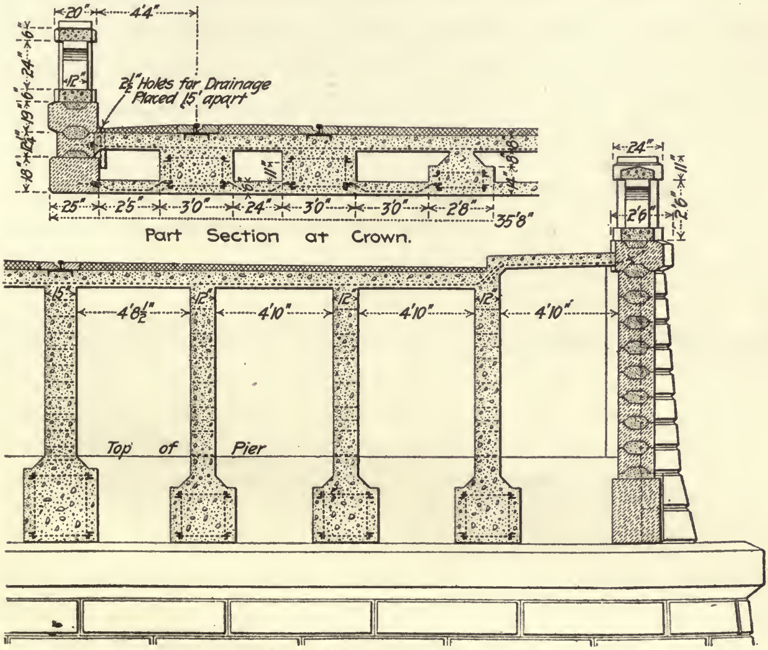


Fig. 317.

that proposed by Thomas Telford about 1824 for erecting a 500-foot cast iron arch over Menai Straits, a modification of which was used on the Eads bridge at St. Louis. Concrete steel forms for the two arch ribs were supported by guy ropes from temporary towers on the piers and abutments. The ribs are 9 feet apart on center, 24 inches thick and 32 inches deep at the crown, increasing to 50 inches at the springs, not including the thickness of the forms, which have 3-inch sides

and 4-inch bottoms. The ribs are braced together with eight cross walls in each span, 21 inches thick between the ribs and 12 inches thick above. Between the piers are similar ones, which, together with 12-inch spandrel walls, support the 6-inch floor slab and track ballast. The forms for each rib are divided into seventeen voussoirs about 5 feet long, weighing 1,500 to 2,200 pounds each. They are dowelled together and were placed with a wood traveler on a temporary wood bridge, though a cable way might have been more convenient. A two-span ribbed arch was also built by Mr. Strauss at Howard Street, Spokane (Fig. 318), with six ribs and open spandrels. The plan shows brick paving between the car tracks and as-

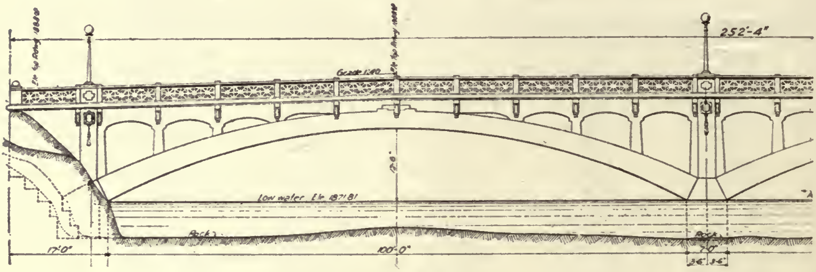


Fig. 318.

phalt at the sides, on a floor slab supported by 12-inch cross walls about 10 feet apart through the central portion, and on spandrel columns and floor beams near the ends.

The Jamestown bridge, built in 1907 by the United States Government to connect the outer ends of two piers, is of reinforced concrete for pedestrian travel only, the ascent of the roadway being made by a series of steps and landings. Two reinforced concrete ribs carry the roadway on four longitudinal walls. Abutments are cored out, and each one rests on 26 plumb and 126 batter piles. The Boulevard bridge at St. Paul, with a central span of 110 feet has three reinforced concrete ribs with open cross spandrels and a floor width of

40 feet. At each end are approach spans, making the bridge 222 feet long. The Wakeman, Ohio, bridge over the Vermillion river (1908) is a ribbed arch and a cantilever with brackets 37 feet long at each end. It has two three-hinged arch ribs with open spandrels and a floor slab supported on beams and columns, the whole being proportioned for 18-ton wagons or rollers. Wilbur J. Watson, engineer.

461. The first **concrete cantilever** bridge in the United States was at Marion, Iowa (1905), for the Marion Street Railway Company. It has three 50-foot spans with two longitudinal ribs 12 inches wide supported on concrete columns, and a floor slab on transverse beams. The bridge has very light abutments in comparison with an arch, and a proportionately less cost. The two-span arch over Charley Creek at Wabash, Ind. (1905), was designed with cantilever spandrel walls. In 1906 the Belvidere bridge, previously described, was erected by cantilever methods, and in 1907 a two-ribbed highway bridge was placed across the Rhone at Pyrimont, with a cantilever arm at one end. The Wakeman bridge followed in 1908, and in the same year a three-span concrete cantilever bridge for the Newcastle and Toledo Electric Railway, with center and end spans of 60 and 20 feet, respectively. The bridge is 16 feet wide, with side girders 26 inches wide and 7 feet deep, with a 20-inch floor slab, the appearance being that of a half-through girder bridge. An enclosed or tubular concrete foot bridge of four spans was erected in 1909 at Southbridge, Mass., the clear width and height being 10 and 8 feet, respectively. It carries pipes over the river to a manufactory.

462. Three large bridges of unusual interest are those at Emerichsville, Ind. (1905), Cedar Rapids, Iowa (1906), and Waterville, Ohio (1908). The Emerichsville bridge, over the Whitewater river, has an entrance archway over the road at the park end, and the arches are ornamented on the face and

spandrels with panelled work, with elaborate moldings above the piers. The adjoining boulevards and landscape gardening tend to make it attractive.

The Cedar Rapids bridge, in two sections with four spans in each, is divided in the middle by an island in the Cedar river. All spans are 75 feet long, with 7-foot rise, and piers are 7½ feet thick at the springs. Arches are three-centered, 16 inches thick at the crown and 36 inches at the skewbacks, and are reinforced with lattice frames 3 feet apart. It was under construction from April, 1905, to January, 1906. The Maumee river bridge at Waterville, Ohio, has twelve spans of 75 to 90 feet, with a 25-foot rise. The total length is 1,200 feet, and the 16-foot deck is 45 feet above low water. It carries a single track of the Lima and Toledo Traction Company over the Maumee river fifteen miles southwest of Toledo and contains 9,200 cubic yards of concrete and 100 tons of steel. (Fig. 326.) It is the work of Mr. Daniel B. Luten, designer and builder of many fine concrete bridges throughout America.

463. Reinforced concrete bridges differ so greatly from those of solid masonry that a great variety of patents have been secured on special types and features, and on different kinds of reinforcing bars and frames. Many of these patents are owned by a few companies making a specialty of concrete bridge construction, and the patented features include cored abutments, double arches, pavement ties, hinges, unsymmetrical end spans over sloping ground, portal features, T-shaped arches, trussed slabs and collapsible centers. An 8-inch curved slab with 28-inch rise was used on a 40-foot span near Albany, Ind. (1905), the slab being trussed with ribs 4 feet apart. Double arch rings one above the other with earth filling between them, were used (1905) on a bridge near Muncie, Ind., the rings being united at intervals of about 8 feet with web ties. The object in the special form was to

eliminate inefficient material near the neutral axis of the arch section. The Kissinger bridge (1907), southeast of Wabash, Ind., has a concrete arch rib 8 feet wide with a single central spandrel wall on which a flat floor slab 16 feet wide is supported and balanced.

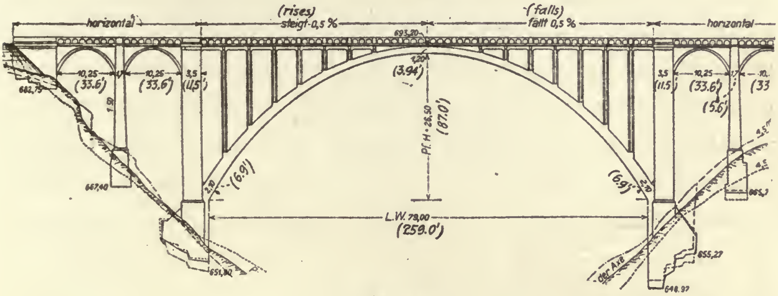


Fig. 319.

464. The longest reinforced concrete arch completed, not including those which are proportioned like solid masonry arches, is the **Stein-Teufen** bridge (Fig. 319), Switzerland (1909), with a central span of 259 feet. The main piers are reinforced to resist unbalanced thrusts from the adjoining arches. The main arch rings are 21½ feet wide and 4 feet thick at

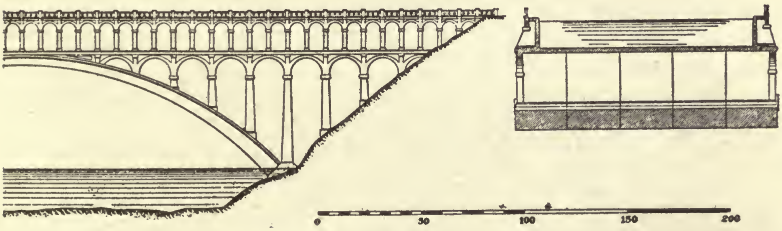


Fig. 320.

the crown, reinforced with 1⅛-inch round bars 10 to 18 inches apart. The bridge has a Telford pavement, and sidewalks 2 feet wide on concrete slabs supported on stringers and spandrel columns. The concrete balustrade has openings 3 feet wide, guarded with embedded bars. A longer span of 285 feet

is projected to carry the New York State barge canal over a gorge near Medina, N. Y. (Fig. 320.) Previous to making designs for this bridge, elaborate experiments on arches were undertaken at Albany, May, 1910, under the direction of the state engineer, the model arches having 8-foot spans and crown thickness of 2 inches. But the longest masonry arch of any kind, either stone or concrete, is now (1910) under construction to cross the Tiber river at Rome with a single span of 328 feet. It will be 65½ feet wide and is estimated to cost $250,000. The next longest span is the Plauen arch in Germany, with a span of 295 feet. It is appropriate that Rome, where some of the first arch bridges appeared, should also have

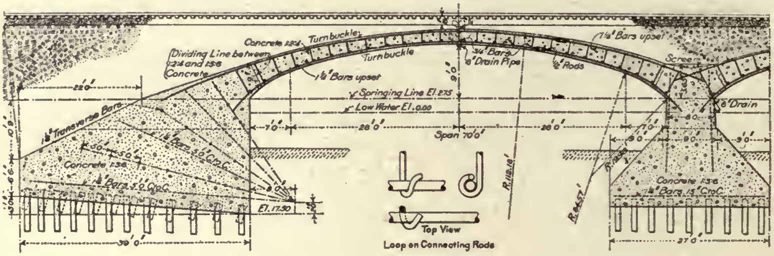


Fig. 321.

the longest modern span. The longest series of reinforced concrete arches are the bridges at Sandy Hill, 1,025 feet; Waterville, 1,200 feet; Glendoin, 1,019 feet; Austin, 1,000 feet; Boston, 1,740 feet, and Galveston, 2,455 feet.

465. The **Galveston bridge** (Fig. 321), with a long series of arches somewhat similar to those at Key West, crosses the bay from the city to the mainland. In addition to the twenty-eight spans of 70 feet, there is also a rolling lift bascule with 100-foot clear opening. The viaduct, 2,455 feet long, is only a part of the whole causeway over two miles in length, the remaining portion being embankment faced with a slab of concrete. Provision is made for three lines of railway on one

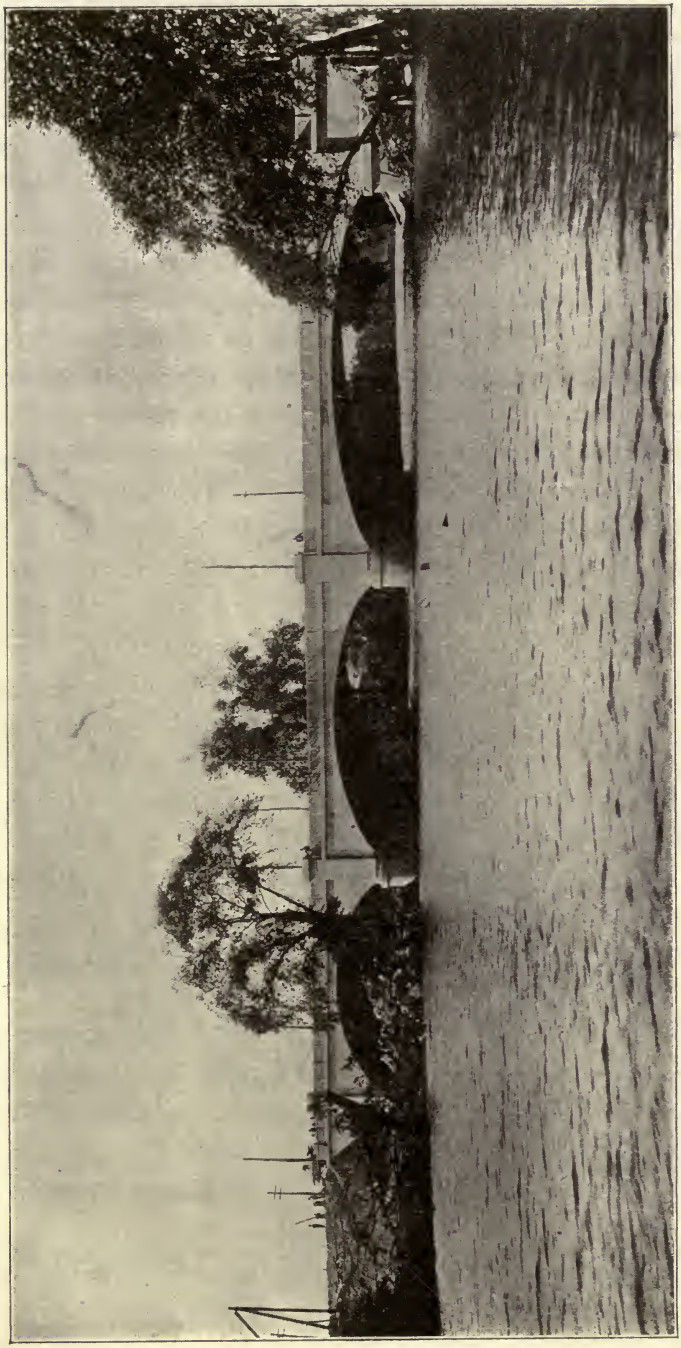


Fig. 323.

side, and a 19-foot highway on the other side, the whole width being 66 feet. The deck is 16½ feet above low water, which has average depth of 5 feet. Other notable bridges of 1910 are at Toulouse, Constantine, Kansas City, Dallas, and Weston. The bridge at Toulouse over the Garonne river, is 730 feet long and consists of two separate bridges side by side, with five pairs of elliptical arches, the largest or center pair having an opening of 150 feet. Each arch of the pair is 10 feet wide and they are separated by an interval of 33 feet, which is spanned by a floor framing in reinforced concrete, the total width of deck being 70 feet. The masonry arch at Constantine, Algeria, is 330 feet above the Rummel River and is one of the highest of its kind. It is 1475 feet long, and contains twenty-seven arches of unequal length, the largest being 230 feet. The twin arch rings are 13 feet apart as in the Luxemburg bridge, and they are connected at the crown by a plate of reinforced concrete. The Kansas City concrete bridge, with a length of 2500 feet, has a series of arches from 50 to 200 feet, each having four concrete ribs, supporting a 40-foot roadway and two 10-foot walks.* One of the longest concrete bridges is now (1911) under construction between Dallas, Texas, and the suburb of Oak Cliff. It is 5106 feet long and crosses a shallow valley which, though usually dry, is occasionally flooded from the Trinity river. The bridge contains fifty-one arches with a clear span of 71½ feet, in addition to the river span and end trestle approaches. The arches are reinforced curved slabs 39½ feet wide, varying in thickness from 16 inches at the crown to 36 inches at the springs, and the open spandrels support a 56-foot deck. Every fifth pier is thicker than the rest and is proportioned as an abutment. Its total cost will be about $570,000, or

*It is not far from the old railroad bridge built under the direction of Mr. Octave Chanute, who was one of the foremost bridge and railroad engineers of America.

$2.10 per square foot. The longest concrete arch in Canada is the **Wadsworth bridge** over the **Humber at Weston,** Ontario, with a span of 118½ feet. It was completed in 1910, and replaced an old timber bridge built about thirty-five years ago by William Tyrrell, of Weston, who for twenty-five years was Reeve of the Township of York, and Warden of York County, and under whose direction this and many other bridges in the district were built.

466. Other fine bridges in America are at Pittsburg, Boston, Los Angeles and Milwaukee. The **Meadow Street** bridge

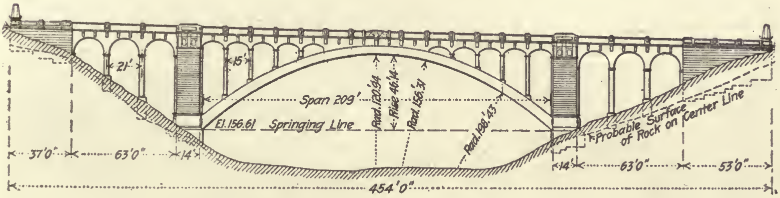


Fig. 322.

(Fig. 322) at Pittsburg, 50 feet wide, is one of the best and the largest one of the kind in that district. The center opening is 209 feet, and at each side are three approach spans, making a symmetrical arrangement. In the center span are three reinforced concrete arch ribs whose curve approaches a parabola, the ribs being connected by struts at the panels, and the deck supported on spandrel beams and columns 15 feet apart. It is the work of Mr. Willis Whited, and cost $65,000. The new Charles river bridge at Boston, Mass., for the Boston Elevated Railway Company, will contain nine river spans of 98 to 122 feet, with lift spans at each end, the total length of bridge being 1,740 feet. The deck is 31 feet wide inside of parapets, with accommodation for two lines of track and a 4-foot walk at each side. In each span are two reinforced concrete arch ribs 29 feet apart on center, with end hinges, and under each rail is a line of steel beams. The spandrel faces

are enclosed with 8-inch curtain walls. Two fine bridges have recently been completed at Seventh Street and Main Street, Los Angeles, each having three spans and widths of about 70 feet. The Seventh Street bridge has 80-foot elliptical slab arches with spandrel face walls and earth filling. Arch rings have a thickness at the crown of 18 inches under the roadway, and 24 inches under the two lines of car tracks. Piers and abutments are hollow, the piers being 8 feet thick at the

Fig. 324.

springs. The total cost was $105,000. Main Street bridge contains most of the best features of economical design, useless material being eliminated as far as possible. Piers and abutments are hollow, and the deck is supported by spandrel beams and columns on eight lines of three-hinged reinforced arch ribs. Both these bridges are the design of Mr. H. G. Parker. A fine example of ribbed arch design was submitted in 1908 for the Grand Avenue viaduct in Milwaukee, which has lately been completed on another plan.

Other small American bridges are at Riverside Drive, Derby and Mishawaka. The Derby bridge (Fig. 323) has a

panelled balustrade of unusual design—heavy and substantial —giving a feeling of security over dangerous or rapid water. A much lighter one is used on the Mishawaka bridge, which has a metal balustrade between concrete pedestals above the piers. The two-span bridge at Reno (Fig. 324), has elliptical arches, and a foot bridge with solid curving balustrade is illustrated in Fig. 325, while Fig. 326 is made without any balus-

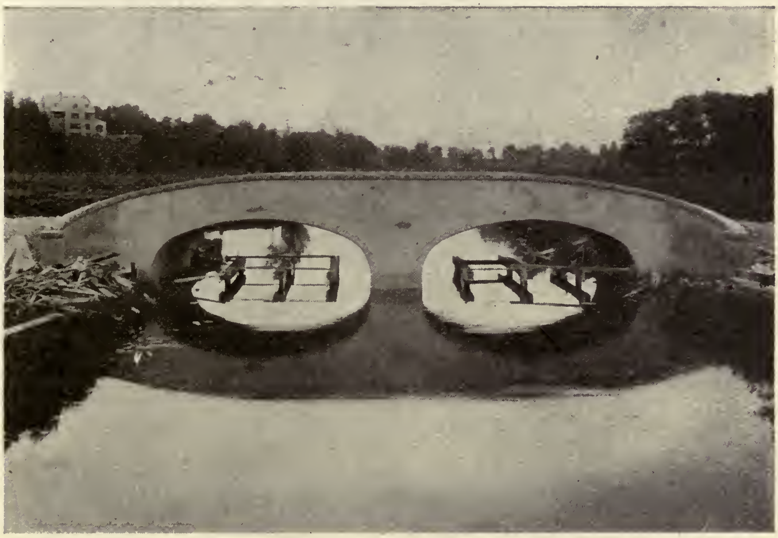


Fig. 325.

trade. The Market bridge at Monterey, Mexico (Fig. 327), is enclosed somewhat similar to Pont Vecchio and the Rialto.

467. Bridges of the **most economical** design and least cost are those at Stockbridge, Forest Park, Oconomowoc, Waterloo, Plainwell, Kankakee, Greensburg, Peru, and Sandy Hill, with costs of $1.44 to $2.15 per square foot of roadway surface.

468. **Failures** have occasionally occurred, and expensive lessons have thereby been learned. Complete or partial failures happened to bridges at Peoria, Edinburg, Mamaroneck,

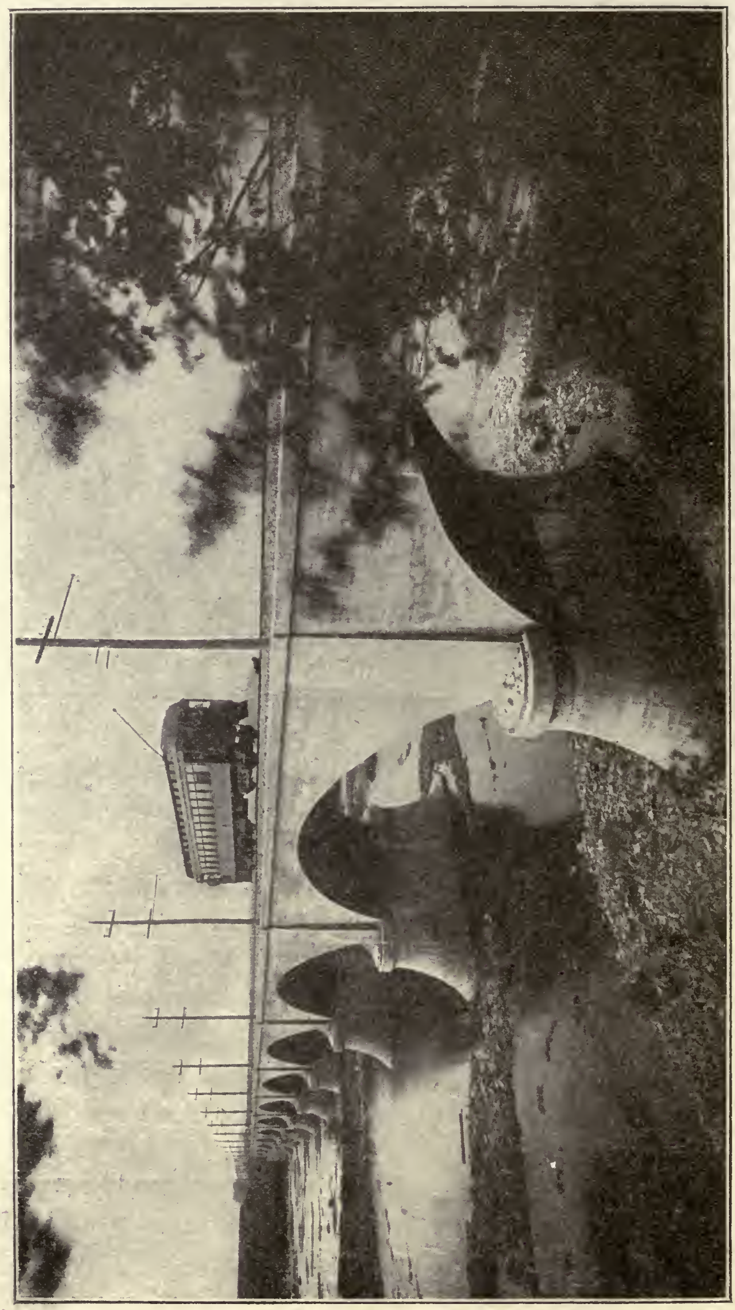


Fig. 326.

and Pasadena. The highway bridge over Flat Rock river near Edinburg, Ind., which failed February 28, 1910, had been in use for eight months. Of the three spans the center one had an opening of 90 feet, and the side ones 75 feet each. A bridge at Mamaroneck, N. Y., with five small spans of about

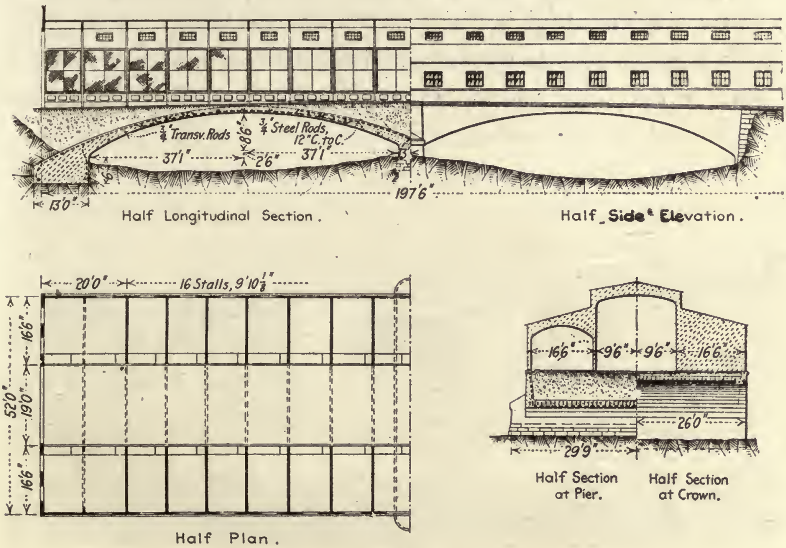


Fig. 327.

20 feet each, partially failed in 1904. All of these failed because of scour at the foundations. The Pasadena bridge, designed by Michael De Palo, and built by Carl Leonard of Los Angeles, was examined in 1907 by the writer, after its partial failure, and a report made on repairing it. The side girders were badly cracked and sagged from their original position, and the center span was blocked up on timber work. After much delay the timber tower was replaced with an additional concrete pier, holes being cut through the floor for its connection. Cracks were enlarged and refilled solid with concrete (Fig. 328).

469. The design of highway bridges in the State of Illinois

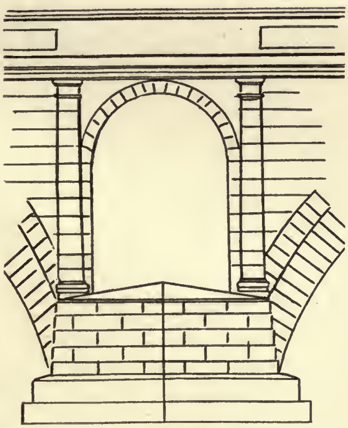
has lately been placed under the supervision of the **State Highway Commission,** thus bringing them under government supervision, as has been done in some foreign countries. It has become a duty of this Commission to undertake the engineering work for highway bridges, and to prepare surveys with complete designs, estimates, plans and specifications. These are supplied to municipalities in the state, free of charge. Notices are also sent to construction companies, and instructions given to municipal officers in reference to awarding contracts.

Fig. 328.

The movement is somewhat similar to that adopted by the French government in the middle of the eighteenth century, when a Department of Bridges and Highways was established under the direction of Perronet, or to the later movement in Great Britain, when more than twelve hundred bridges were erected throughout the islands under the direction of Thomas Telford.

470. The **general tendency** in the construction of concrete railroad bridges has been towards the use of solid arch rings proportioned like masonry arches, reinforcement being introduced not to resist tension, but rather to unite the materials

into a solid monolith. As weight and mass are essential to security under heavy moving loads, the preference in railroad bridges has been for either solid spandrel filling, or open spandrels with 4 to 5 feet of earth and ballast beneath the track. The tendency in highway bridges, reinforced to resist bending stresses from moving loads, has been to proportion arch rings so that line of pressure will lie within the middle third for uniform loading. For highway bridges, open spandrels with projecting sidewalks are preferred to solid spandrel filling, and ribbed arches, sometimes with cantilever ends, are proving more economical than arches with solid slabs. Wide structures with slab arch rings are now generally made with double rings 10 to 15 feet apart, the space between them at the deck being bridged with the regular floor construction of beams and slabs.



PONS FABRICIUS

ERRATA

Page 22. Caption "Ponte Rotto" should read "Pons Fabricius."

Page 43. Lines (2-3-4) and (6-7) should be reversed.

Page 118. Paragraph 157, omit line 3.

Pages 102, 178, etc., word Morrison should read Morison.

Page 425. Line 29, word "Menser" should read "Mueser."

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NAMES OF JOURNALS, WITH ABBREVIATIONS

A. A.	American Architect.
A. & B. M.	Architects and Builders Magazine.
C. E. N.	Canadian Electrical News.
C. E.	Canadian Engineer.
C. & B.	Carpentry and Building.
The Eng.	The Engineer, London.
Engin.	Engineering, London.
E. & M. J.	Engineering and Mining Journal.
E. C.	Engineering Contracting.
E. N.	Eningeering News.
E. R.	Engineering Record.
El. E.	Electrical Engineer, London.
El. Rev.	Electrical Review, London.
El. W.	Electrical World.
Elec.	Electricity.
F. M.	Feilden's Magazine.
I. & E. E.	Indian and Eastern Engineer.
I. A.	The Iron Age.
M. J. & E.	Municipal Journal and Engineer.
R. R. G.	Railroad Gazette.
R. & E. R.	Railway and Engineering Review.
S. A.	Scientific American.
S. R. R.	Street Railway Review.
T. U. E. J.	Toronto University Engineering Journal.
W. E.	Western Electrician.
W. B.	Ossterr-Wochenschrift. d. offentl. Baudienst.